NYPL RESEARCH LIBRARIES
3 3433 08996926 9

B VHI
Frenc
[illegible]

REPORT

OF THE

(FRENCH) COMMISSION

ON THE

USE OF EXPLOSIVES

IN THE

PRESENCE OF FIRE-DAMP IN MINES.

TRANSLATED BY

W. J. BIRD AND M. WALTON BROWN.

NEW YORK
PUBLIC
LIBRARY

NEWCASTLE-UPON-TYNE:
PRINTED BY ANDREW REID, SONS & CO., 50, GREY STREET.
1890. [i.e. 1891]
EK

PREFACE.

This translation of the Reports of the French Commission on the Use of Explosives in the Presence of Fire-damp in Mines was made by Messrs. W. J. Bird and M. Walton-Brown, for the use and information of the Explosives Committee of the North of England Institute of Mining and Mechanical Engineers, and is issued to the Members of the Institute by order of the Council.

Mr. W. J. Bird unfortunately did not live to see the publication of the translation. He received an appointment as engineer to the Persian Bank Mining Rights Corporation, Limited. Arriving at Bushire, in Persia, on September 1st, 1890, he left that port on September 14th, and speedily took up his duties by exploring for coal and other minerals, in the neighbourhood of Narrestoon, in the Ghisakhun mountains. While engaged at his explorations for the Corporation, he was seized with remittent fever, and died on October 14th, 1890, at the Borasjoon caravanserai. His assistants, Mr. William Bainbridge and Mr. Alfred Alder, had his body conveyed to Bushire, and he was buried on October 15th, by an ordained minister of the Greek Church, in the Armenian Cemetery at Bushire.

February 20th, 1891.

S2 P3 21 Sept 1934

CONTENTS.

REPORT OF THE (FRENCH) COMMISSION ON THE USE OF EXPLOSIVES IN THE PRESENCE OF FIRE-DAMP IN MINES ... ... PAGE 1
HISTORICAL 1
French Commission 1
English Commission 1
Prussian Commission 3
Dynamite 3
Blasting-gelatine 3
Gelatine Dynamite No. I. 3
Gelatine Dynamite No. III. 4
Compressed Gun-cotton 4
Gun-cotton mixed with 50 per cent. of Nitrate of Barium ... 4
Hellhoffite 4
Carbonite 4
Kinetite 4
Securite 4
Roburite 4
Lithotrite 5
Schultze Powder 5
Detonators 5
Safety Fuse 5
Water Cartridges 5
Wetter-dynamite 6
Saxon Commission 6
Austrian Commission 6
Action of Coal-dust 7
Commission appointed by the Minister of Public Works ... 8
CHAPTER I. 9
Description of the Apparatus and Methods of Experimenting ... 9
Apparatus for Generating Marsh Gas 10
Experimental Boiler 12
Gasometer 13
Boiler and Ejector 13
Mode of carrying out an Experiment 13
Description of Gas used 14
CHAPTER II. 15
Explosives suspended in the midst of Gaseous Mixtures ... 15
Detonators 15
Explosives already known 15
Blasting-powder 16
Dynamite (No. 1 Vonges and No. 0 Paulilles) 16
Ammonia Dynamite of Paulilles 16
Gun-cotton 16
Blasting-gelatine and Gelatine Dynamite 16
Hellhoffite 17
Favier Explosive 17
Bellite 17
Gun-cotton with Nitrate of Barium 18
Pyroxyline Powder from Moulin-Blanc 18
Study of New Explosives, not Igniting Fire-damp 18
Dynamite and Soda Crystals 18
Dynamite and Crystallized Sulphate of Soda 19
Dynamite and Ammonia-alum 19
Dynamite and Sal-Ammoniac 19

PAGE
Dynamite and Coal-dust 19
Dynamite and Lignite Dust (Brown Coal) 20
Dynamite and Nitrate of Ammonia 20
Gun-cotton and Sal-Ammoniac 20
Gun-cotton and Nitrate of Ammonia 20
Theoretical Inquiries 21
Ignition of Gaseous Mixtures 21
Temperature of Detonation of Explosives, Formulæ for its Calculation 22
Pressures Developed by Explosives, Formulæ for its Calculation 24
Comparison of Theoretical with Experimental Pressures ... 24
Experimental Study of the Unconfined Detonation of Explosives 26
Incomplete Detonation of Unconfined Explosives 26
Method of Experimenting 27
Experimental Result for Dynamite, almost completely Detonated Unconfined 28
Experimental Result for Various Explosives 28
Peculiar Phenomena Exhibited by Low-nitrated Cottons, Detonating Unconfined 30
Explanation of the Phenomena presented by Mixtures of Gun-cotton and Nitrate of Barium, Pyroxyline Powder ... 31
Force of Explosives 31
Possible Influence of the Aqueous Vapour contained in Air, on the Inflammability of Fire-damp 32
Summary 32
CHAPTER III.... 34
Explosives Fired in a Closed Vessel 34
Process of Experimenting 34
Experimental Results 34
Explanation of the Effect Produced, as regards the Ignition of Fire-damp by the Tube which envelopes the Explosive; Work Developed by the Bursting of the Sides of the Tube 35
Apparent Temperature of Ignition of Mixtures of Fire-damp and of Air under the Influence of Explosives... ... 36
Explosion amongst Water... 36
Variation of Work Developed by the Gases of the Explosion with Density of Charging 37
Method of Detonation of Various Explosives in a Closed Vessel, Experimental Researches 39
Effect Produced by Explosives Stemmed in a Shot-hole and Ignited with Fuse 40
Summary, General Rule for the use of Explosives in a Fiery Mine 40
CHAPTER IV.... 40
Method of Firing Shots in Mines 40
Detonators, Plugged and Unplugged, Difference of their Effects on the Ignition of Fire-damp 40
Various Detonators 41
Dangers which characterise the Bickford Fuse 41
Use of Electricity 41
Detonating Strings 42
Friction Detonators 42
CHAPTER V. 42
Conclusions 42
TABLE OF EXPERIMENTS MADE AT THE SEVRAN-LIVRY POWDER MILL ... 45
Detonators 45
Unplugged Detonators 45
Unplugged Detonators lapped externally with Copper Wire ... 45
Plugged Detonators 45
Paulilles Detonators 45
Abegg Detonators 46
Ruggieri and Scola Detonators 46
Bickford Fuse 46
Unconfined Cartridges 47
Explosives already known 47

PAGE

- No. 1 Dynamite (Vonges, 75 per cent. of Nitro-Glycerine) 47
- No. 0 Dynamite (Paulilles) 47
- Blasting-gelatine (Paulilles) 47
- Gelatine Dynamite (Paulilles) 48
- Ammonia Dynamite (Paulilles) 48
- Military Gun-cotton in Thin Brass Cases 48
- Mining Gun-cotton, Cartridges wrapped in Paper ... 48
- Gun-cotton (·68 cubic inch of NO_2 per grain)... ... 48
- Pyroxyline Powder (Moulin-Blanc), in rectangular Cartridges, strongly compressed 49
- Gun-cotton and Nitrate of Barium 49
- Gun-cotton (Wetteren) and Nitrate of Barium ... 49
- Favier Explosive 49
- Hellhoffite 49
- Bellite 49
- Various Mixtures 50
  - Mixtures with Dynamite Base 50
    - Mixtures with Crystallized Carbonate of Soda ... 50
    - Mixtures with Crystallized Sulphate of Soda (with 10 equivalents of H_2O) 50
    - Mixtures of Dynamite and Ammonia-alum ... 50
    - Mixtures with Sal-Ammoniac 50
    - Mixtures with Dust of Combustible Minerals ... 50
    - Mixtures with Nitrate of Ammonia 51
  - Mixtures with Gun-cotton Base 51
    - Mixtures of Sal-Ammoniac with Mining Gun-cotton 51
    - Mixtures with Nitrate of Ammonia 51
      - Military Gun-cotton (·81 cubic inch of NO_2 per grain) 51
      - Mining Gun-cotton (·76 cubic inch of NO_2 per grain) Cartridges probably damp 51
      - Gun-cotton (·68 cubic inch of NO_2 per grain) ... 51
- Enclosed Cartridges 52
  - Experiments on Various Explosives 52
  - Experiments on the Influence of the Density of Charging ... 53
  - Experiments on Ignition of Explosives by Fuse 53
- Experiments on the Settle Cartridges 54
- Experiments with Coal Dusts 54
- Experiments on Detonation in the Closed Boiler 55

NOTE A—ON THE CALCULATION OF THE TEMPERATURES OF DETONATION AND THE POWER OF EXPLOSIVES 57

- Theoretical Calculation of the Temperature of Detonation ... 57
- Formula of Clausius.—Co-volumes 58
- Calculation of the Explosive Force 58
- Mode of Decomposition of an Explosive 59
- Mode of Decomposition of Nitric-cotton 61
- Table of the Temperatures of Detonation and Explosive Forces of Various Explosives 62
  - Simple Explosives 63
    - Dynamite (75 per cent.) 63
    - Nitrate of Ammonia 63
    - Picric Acid 63
    - Gun-cottons 64
      - Endecanitric Cotton 64
      - Octonitric Cotton 64
    - Nitromannite 64
  - Dual Explosives 64
    - Bellite, 80 Nitrate of Ammonia and 20 Dinitro-benzol 64
    - Favier Explosive 64
    - Mixtures of Dynamite and Nitrate of Ammonia ... 65
    - Mixtures of Gun-cotton with Nitrate of Ammonia ... 65
      - Endecanitric Cotton 65
      - Octonitric Cotton 65
    - Octonitric Cotton and Nitrate of Barium 66
    - Blasting-gelatine 66

PAGE
Comparison between the Calculated Pressures and the Pressures Experimentally observed 66
Deductions as to the Law of the Co-volume and the Value of that Co-efficient 67
Deductions as to the Variation of the Specific Heats of the Condensed Gases with Temperature and Pressure ... 68
Deductions as to the Existence of the Variation with the Temperature of the Specific Heat of Perfect or Non-condensible Gases 68
Deductions as to the Rate of Increase with Temperature of the Molecular Specific Heat of Perfect or Non-condensible Gases 69
NOTE B—ON THE QUANTITY OF HEAT WHICH CAN BE TRANSFORMED INTO WORK BY THE ADIABATIC EXPANSION OF A GAS ... 71

SUPPLEMENTARY REPORT OF THE (FRENCH) COMMISSION ON THE USE OF EXPLOSIVES IN THE PRESENCE OF FIRE-DAMP IN MINES 75
Explosives in Presence of Mixtures of Air and Coal Gas ... 75
Influence of Aqueous Vapour upon the Inflammability of Fire-damp Mixtures 76
On the Method of Detonation of Explosives 76
Mode of Conducting the Experiments 77
Unconfined Detonation 77
Detonation in Resisting Vessels 77
Experimental Researches 79
Simple Explosives 79
Dual Explosives 80
The Gases of the Detonation are incapable of Mutual Reaction 81
Mixtures of Dynamite and Nitrate of Ammonia 81
Unconfined Detonation 81
Detonation in Resisting Vessels ... 81
Various Mixtures 82
The Gases from the Detonation are capable of Mutual Reaction 82
Unconfined Detonation 82
Mixtures of Octonitric Cotton and Nitrate of Ammonia 82
Mixtures of Dinitro-benzol and Nitrate of Ammonia 84
Mixtures of Picrate and Nitrate of Ammonia 84
Various Mixtures 84
Summary 85
Detonation in a Massive and Resisting Vessel 85
Detonation in a Tin Tube 0·98 inch and 1·22 inches diam. 85
Study of Explosives affording Guarantees of Safety 86
Detonation in Tin Tubes 0·98 inch and 1·57 inches diam.... 87
Mixtures of two Combustion-Supporting Substances ... 88
Mixtures of Dynamite and Nitrate of Ammonia ... 88
Mixtures of a Combustion-Supporting Substance and a Combustible Substance 90
Mixtures of Gun-cotton and Nitrate of Ammonia... 90
Mixtures of Dinitro-benzol and Nitrate of Ammonia 91
Mixtures of Mononitronaphthalene and Nitrate of Ammonia 92
Mixtures of Naphthalene and Nitrate of Ammonia... 92
Mixtures of Coal-Tar and Nitrate of Ammonia ... 94
Mixtures of Heavy Oils from Coal-Tar with Nitrate of Ammonia 94
Mixtures of Resin with Nitrate of Ammonia ... 95
Mixtures of Picrate of Ammonia and Nitrate of Ammonia 95
Mixtures of Nitrate of Cupro-Ammonia and Nitrate of Ammonia 95

PAGE
- Conclusions 99
- TABLE OF EXPERIMENTS MADE AT THE SEVRAN-LIVRY POWDER MILL 102
  - Experiments made in Combustible Gases 102
    - Combustible Gases, containing ·103 of Fire-damp and ·897 of Air, by Volume 102
      - Detonators 102
      - Dynamite and Nitrate of Ammonia 102
      - Octonitric Cotton and Nitrate of Ammonia ... 103
      - Nononitric Cotton (Mining Cotton) and Nitrate of Ammonia 103
      - Mononitronaphthalene and Nitrate of Ammonia ... 103
      - Naphthalene and Nitrate of Ammonia ... 104
      - Dinitro-benzol and Nitrate of Ammonia ... 104
      - Picrate of Ammonia and Nitrate of Ammonia ... 104
      - Resin and Nitrate of Ammonia 104
      - Coal-Tar and Nitrate of Ammonia 105
      - Heavy Coal Oil and Nitrate of Ammonia ... 105
      - Nitrate of Cupro-Ammonia and Nitrate of Ammonia 105
    - Combustible Gases, containing ·103 of Coal-gas and ·897 of Air, by Volume 105
      - Dynamite and Nitrate of Ammonia 105
      - Octonitric Cotton and Nitrate of Ammonia ... 106
      - Naphthalene and Nitrate of Ammonia ... 106
      - Nitrate of Cupro-Ammonia and Nitrate of Ammonia 106
      - Various Explosives 106
  - Experiments on Detonation in the Close Boiler, containing Air only 107
      - Dynamite and Nitrate of Ammonia 107
      - Octonitric Cotton and Nitrate of Ammonia ... 108
      - Dinitro-benzol and Nitrate of Ammonia ... 109
      - Mononitronaphthalene and Nitrate of Ammonia (Favier Explosive) 109
      - Naphthalene and Nitrate of Ammonia... ... 109
      - Picrate of Ammonia and Nitrate of Ammonia ... 110
      - Heavy Tar Oils and Nitrate of Ammonia ... 110
      - Coal-Tar and Nitrate of Ammonia 110
      - Nitrate of Cupro-Ammonia and Nitrate of Ammonia 111
      - Nitromannite 111
      - Various Explosives 112

- PRACTICAL EXPERIMENTS IN COLLIERIES ON EXPLOSIVES COMMENDED BY THE EXPLOSIVES SUBSTANCES COMMISSION 113
  - SUMMARY OF THE REPORTS ON THE EXPERIMENTS 113
      - Mixtures containing either Naphthalene or Nitrate of Cupro-Ammonia 114
      - Mixtures containing Nitro-glycerine 114
      - Mixtures containing either Gun-cotton or Dinitro-benzol 117
      - Instantaneous Fuse 117
      - Appendix 118
  - FIRST SERIES OF EXPERIMENTS 119
    - Anzin Collieries... 119
      - Report of the Practical Experiments with the Explosives received from the Sevran-Livry Powder Mills ... 119
        - Preliminary Experiments 119
        - Comparison with Blasting-powder 120
          - Experiments in Coal 120
        - Comparison with Blasting-gelatine 122
          - Experiments in Stone 122
        - Conclusions 124
        - Instantaneous Fuse 124
    - Blanzy Collieries 125
      - Trial of the New Explosives from the Sevran-Livry Powder Mills 125

PAGE

      - Explosives ... 125
      - Instantaneous Fuse ... 125
  - Firminy Collieries ... 127
    - Report on the Practical Experiments made at the Firminy Collieries, at the request of the Explosives Substances Commission ... 127
      - Difficulties or Disadvantages ... 127
      - Useful Effect ... 128
      - Condition of the Detached Coal ... 128
      - Economic Results ... 128
      - Instantaneous Fuse ... 128
  - Ronchamp Collieries ... 129
    - Experiments with the Explosives sent from the Sevran-Livry Powder Mills ... 129
- SECOND SERIES OF EXPERIMENMS ... 130
  - Anzin Collieries ... 130
    - Report on the Trials made with Explosive Mixtures sent from the Sevran-Livry Powder Mills ... 130
      - Mixture of 20 parts of Nitrate of Cupro-Ammonia and 80 parts of Nitrate of Ammonia ... 131
      - Mixture composed of 70 parts of Nitrate of Cupro-Ammonia and 30 parts of Nitrate of Ammonia ... 131
      - Mixture composed of 5 parts of Naphthalene and 95 parts of Nitrate of Ammonia ... 132
      - Mixture composed of 20 parts No. 1 Dynamite and 80 parts of Nitrate of Ammonia ... 132
      - General Observations ... 132
      - Conclusions ... 133
  - Firminy Collieries ... 134
    - Report on the Second Series of Practical Trials made in the Firminy Collieries, at the request of the Explosives Substance Commission ... 134
  - Blanzy Colliery ... 134
    - Report on the Trials of the Explosive Mixtures from the Sevran-Livry Powder Mills ... 134
      - No. 1 Explosive, 20 parts of Dynamite and 80 parts of Nitrate of Ammonia ... 134
      - New Mixtures ... 134
  - Ronchamp Collieries ... 135
    - Experiments on the Dual Explosives sent from the Sevran-Livry Powder Mills ... 135
- SUPPLEMENTARY DOCUMENTS ... 136
  - Anzin Collieries ... 136
    - On Explosive used at the Anzin Collieries ... 136
      - Historical ... 136
      - First Explosive Used ... 136
      - Second Explosive Used ... 136
        - 12 to 14 parts of Gelatinised Nitro-glycerine and 88 to 86 parts of Nitrate of Ammonia ... 137
        - 20 parts of Gelatinised Nitro-glycerine and 80 parts of Nitrate of Ammonia ... 138
        - 30 parts of Gelatinised Nitro-glycerine and 70 parts of Nitrate of Ammonia ... 138
      - Experiments with the New Explosives with Blown-out Shots ... 138
      - Nature of Fumes ... 138
    - On the use of the Hundredweight of Explosives received from Sevran-Livry Powder Mills ... 139
      - Mixture of 10 parts of Dinitrobenzol and 90 parts of Nitrate of Ammonia ... 139
      - Mixture of 10 parts of Octonitric Cotton and 90 parts of Nitrate of Ammonia ... 139
      - Advantages and Inconveniences of these Explosives... 140
  - Lievin Collieries ... 141
      - On the Explosives in use at Lievin Collieries .. 141

PAGE
MISCELLANEOUS NOTES ON THE USE OF EXPLOSIVES IN THE PRESENCE OF FIRE-DAMP IN MINES... ... 143
Experiments at Anzin on the Flame produced by Explosives 143
Stemming with Water-saturated Substances 144
Lauer Detonators 145
Heath and Frost's Lamp for Ignition of Safety Fuse ... 146
Continuation of the Austrian and Prussian Experiments ... 146
Austrian Commission 146
Prussian Commission 148
Blown-out Shots 149
The Schlesbusch Experiments 151
Summary 151
APPENDIX 153
Anzin Collieries... 153
Experiments with Lauer Detonators 153
Description of the Detonators 153
Results obtained 154
Comparison of the Costs of the Various Systems of Firing, and of the Time occupied in Firing one Shot 154
Conclusions 154
Remarks 155
The Heath and Frost Lamp 155
Use of the Lamp 155
Description of the Lamp 155
Method of Using the Lamp 156
Discussion on the Value of the Lamp 156
Conclusions 157

DECREE OF THE PRESIDENT OF THE (FRENCH) REPUBLIC OF 26TH JULY, 1890, RELATIVE TO THE SALE OF DYNAMITE IN CARTRIDGES 158

REGULATION OF THE EXPLOSIVES TO BE USED IN FIERY MINES, AND IN DUSTY MINES WHOSE DUSTS ARE INFLAMMABLE 159
Circular of August 1st, 1890, to the Prefect 159
Model of the Prefectoral Decree 161
Appendix relating to Article 2 of the Decree 163

Issued 14th AUGUST, 1890.

NORTH OF ENGLAND INSTITUTE
OF
MINING AND MECHANICAL ENGINEERS.

FOUNDED, 1852.—INCORPORATED BY ROYAL CHARTER, 1876.

REPORT OF THE FRENCH COMMISSION ON THE USE OF EXPLOSIVES IN THE PRESENCE OF FIRE-DAMP IN MINES.

THIS REPORT, ALTHOUGH ISSUED TO ALL THE MEMBERS OF THE INSTITUTE
BY ORDER OF THE COUNCIL, IS PRINTED PRIMARILY FOR THE
USE OF THE EXPLOSIVES COMMITTEE.

Newcastle-upon-Tyne:
PRINTED FOR THE PUBLISHERS BY LAMBERT & Co., LIMITED.
1890.

VH
Fren
Substan

SUBSCRIPTIONS.

The Annual Subscription of a Member is Two Guineas, of an Associate Member Two Guineas, of an Associate One Guinea, and of a Student One Guinea.

These Subscriptions are due and payable on the First Saturday of August in each year, in advance for the ensuing year, or immediately after election.

Forms for the nomination of New Members may be had on application to the Secretary.

On Change of Residence, Members will oblige by giving notice thereof to the Secretary, G. A. Lebour, Neville Hall, Newcastle-upon-Tyne.

TRANSACTIONS.

Volumes I. to XXXVI. of the Transactions (excepting Vols. III., IV., V., VI., and XXI., which are out of print) can be had of the Publisher, price 21s. each.

Vol. XXIII., containing the large Map of the South Wales Coalfield, is published at 26s. Single Copies of the Map 10s. 6d.

DUPLICATES.

Notice is always given to Members in the first circular which is issued when a Part of the Transactions is published, and in the case of non-receipt immediate intimation should be given to the Secretary, as by the Rules of the Institute a duplicate copy can only be obtained by making a written application to the Council; and Parts cannot even then be had if they have been stitched together into volumes.

The following works published by the Institute are now ready:—
Price 21s., or Post Free 22s. 2d., A REPRINT OF

VOL. XVII. OF THE TRANSACTIONS OF THE INSTITUTE,

Containing the Report of the Committee on Haulage of Coal Underground.

In Paper Covers, uniform with the Transactions, 5s.; by Post, 5s. 6d.

A GENERAL INDEX TO VOLS. I. TO XXV.

Of the Transactions of the Institute.

Uniform in size with the Transactions,

A Catalogue of the Books and Maps in the Library

of the North of England Institute of Mining and Mechanical Engineers, 260 pp.
Price—To Members, 5s.; to Non-Members, 10s. By Post, 5d. extra.

Royal 8vo, Price 25s. (by Post 25s. 9d.), Containing 64 Illustrations in Autotype,

ILLUSTRATIONS OF FOSSIL PLANTS.

Being an Autotype reproduction of Selected Drawings of Fossil Plants, prepared under the supervision of the late Dr. Lindley and Mr. W. Hutton, between the Years 1835 and 1840. Edited by Professor G. A. Lebour, M.A., F.G.S.

Uniform in Size with the above, Price 8s., by Post 8s. 3d.,

A Catalogue of the Hutton Collection of Fossil Plants,

Including a Synoptical List of the Chief Carboniferous Species not in the Collection. By Professor G. A. Lebour, M.A., F.G.S.

Royal 8vo, Vol. I., 293 Pages. Vol. II., 332 Pages. Vol. III., 329 Pages. Vol. IV., 334 Pages.
Price—To Members 5s. per Volume, except Volume I., 2s. 6d.; by Post 5s. 6d. To Non-Members, 7s. 6d. per Volume; by Post 8s.
PART I. (**A-B**), PART II. (**C-E**), PART III. (**F-K**), AND PART IV. (**L-R**)
of an

Account of the Strata of Northumberland and Durham,

AS PROVED BY BORINGS AND SINKINGS.

This Work, when completed, will comprise the whole of the Borings and Sinkings belonging to the late John Watson, Esq., of Willington, Northumberland, bequeathed by Wm. Watson, Esq., High Bridge, Newcastle-on-Tyne, to the North of England Institute of Mining and Mechanical Engineers. A large number of Borings, &c., furnished by Members of the Institute, are added, forming a complete record of all that has been ascertained by these means of the Geological formation of the two counties of Northumberland and Durham.

☞ *For Officers of the Institute, 1890-91, and Dates of Meeting, see p. 3 of Wrapper.*

France. Substances explosives,
Commission des.

REPORT

OF THE

(FRENCH) COMMISSION

ON THE

USE OF EXPLOSIVES

IN THE

PRESENCE OF FIRE-DAMP IN MINES.

PART I.

TRANSLATED BY

W. J. BIRD AND M. WALTON BROWN.

NEWCASTLE-UPON-TYNE:
PRINTED BY LAMBERT AND CO., LIMITED, 50, GREY STREET.
1890.

EK

THE NEW YORK
PUBLIC LIBRARY
741527 A
ASTOR, LENOX AND
TILDEN FOUNDATIONS
R 1934 L

REPORT

OF THE (FRENCH) COMMISSION (*)

ON THE

USE OF EXPLOSIVES

IN THE

PRESENCE OF FIRE-DAMP IN MINES.

HISTORICAL.

FRENCH COMMISSION ON FIRE-DAMP.

THE French Fire-damp Commission, instituted by law of the 26th March, 1877, had expressed the wish that the Explosive Substances Commission should inquire if, by modifying the character or the method of using explosives, it was possible to diminish the effect of fire-damp explosions resulting from blown-out shots. To that end, Mr. Aguillon, who was willing to give special attention to the question, had temporarily been attached to the Explosive Substances Commission, and made known his conclusions in a report, which was approved at their sitting of 2nd December, 1880.

The Commission was of opinion that, the temperature of ignition of fire-damp being from 1,112 degs. to 1,292 degs. F., there existed no explosive whose detonating temperature was beneath this figure. On the other hand, it was considered as almost impossible to find a process, of which it could be definitely asserted that it prevented with certainty contact of the flame of the explosive with fire-damp.

ENGLISH COMMISSION.

The English Fire-damp Commission, instituted shortly after the French Commission, only terminated its researches in 1886. (†)

Their labours relative to explosive substances were directed by Sir F. Abel, one of the most illustrious members.

(*) This sub-commission is composed of Messrs. MALLARD, Inspector-General of Mines *(President)*; CORNU, Member of the Institute, Engineer-in-Chief of Mines; SARRAU, Member of the Institute, Engineer-in-Chief of Explosives; Colonel SEBERT; Colonel CASTAN; LAMBERT, Engineer-in-Chief of Explosives; Major HAFFEN, of the Engineers; AGUILLON, Engineer-in-Chief of Mines; LE CHATELIER, Engineer of Mines; VIEILLE, Engineer of Explosives; BRUNEAU, Engineer of Explosives *(Secretary)*.

(†) Final Report of Her Majesty's Commissioners appointed to inquire into Accidents in Mines (15th March, 1886). See also "Accidents in Mines," by Sir F. Abel (Minutes of Proceedings of the Institution of Civil Engineers, 24th May, 1887).

S4B 21 Sept 1934 3pts.

It was ascertained that powder enclosed in a shot-hole about 2 feet deep, completely surrounded by water, when blown-out, ignited, four times out of six, a mixture of air and fire-damp. (*)

At Sir F. Abel's suggestion powder was replaced by dynamite, compressed gun-cotton, or gun-cotton mixed with a proportion of a nitrate (saltpetre or nitrate of barium) necessary for the complete combustion of its carbon. In experiments made with blown-out shots it was ascertained that a charge of 3 ounces of dynamite placed at the bottom of a shot-hole 2 feet deep, tamped only with six inches of sand, ignited an explosive mixture of air and fire-damp.

A charge of one of the high explosives above-mentioned, placed at the bottom of the shot-hole and tamped by cylinders full of water (MacNab process), did not ignite mixtures of air and fire-damp, non-explosive by themselves, but rendered inflammable by the addition of a sufficient quantity of coal-dust. Under the same conditions, and with the same mixtures, powder caused ignition.

Sir F. Abel had proposed in 1873 to fire explosives in the midst of water, so as to produce a perfectly equal distribution of the pressure on the sides of the hole. (†) He considered that safety would be obtained by adopting this process. Experiments made in coal showed that though Sir F. Abel's process, had real economical advantages, especially in blasting in coal, it produced almost the same results as the MacNab process as regards safety. Mixtures of air and fire-damp, rendered explosive by dust, were never ignited, but out of 42 shots fired with dynamite, ignition of a mixture of air and fire-damp occurred six times.

Mr. Galloway having proposed to place moss saturated with water immediately above the explosive, the Commission ascertained that this process, except a slight advantage (in simplicity and cheapness), had nearly the same effect as water.

The Commission obtained no satisfactory result by the use of a rather singular process, suggested [by Sir F. Abel, and tried] by Mr. Galloway, which consisted in placing above the cartridge, liquefied carbonic acid gas enclosed in iron cylinders.

Furthermore, they rejected the use for stemming of solid materials, capable of producing under the influence of heat a considerable amount of water or gas, such as crystallised carbonate of soda, carbonate of lime, &c. Sir F. Abel rightly remarked that there would certainly not be time, owing to the suddenness of the detonation, for the expected disengagement to be produced.

To sum up, the English Commission spoke favourably of the use of gelatine-dynamite (as better resisting the action of water). The cartridge being placed at the bottom of the hole, it was recommended that water be poured in to fill the space between the sides of the cartridge and those of the hole, then to stem half the depth of the hole with moss soaked in water, and to complete the filling with water. It was remarked that this process suffices against mixtures of air and fire-damp non-explosive in themselves, but made explosive by the presence of coal-dust, but was only comparatively efficacious when the mixture of air and fire-damp was actually explosive in itself.

The Commission further clearly pronounced against the use of the Bickford fuse, and in favour of electrical firing.

(*) "It was found that out of six powder-shots, consisting of charges of six and eight ounces, in 3-inch holes, having water cylinders 2 feet and 2 feet 2 inches long placed over them, and closely fitting the shot-holes, the blown-out shot fired the surrounding gas mixture in four instances; in a fifth, there was some doubt whether ignition had taken place, and in the sixth, fired under the same conditions, the gas mixture was not ignited."—Final Report, p. 53.

(†) There has been proposed and patented, for the purpose of keeping the cartridge in the midst of the water (under the name of the "settle cartridge"), a bag of impermeable paper, the diameter of the shot-hole, which bag is filled with water, and in the axis of which the explosive cartridge is maintained. With this object the cartridge is fastened in a tin cylinder provided with wings. Sir F. Abel contests the validity of the patent.

PRUSSIAN COMMISSION.

The Prussian Fire-damp Commission, instituted October 6th, 1880, have published the results of their researches from time to time.

Most of their experiments on explosives were made in the course of 1885, and the results, after having been mentioned in several technical journals, were officially published in 1886. (*) Further experiments were made under the same conditions as the earlier ones, from May to September, 1887, and their results have only been published in the later numbers of the Official Mining Journal for 1887. (†)

The experiments of the Prussian Commission were made in a long artificial gallery constructed on the waste heap at the König Colliery, near Neunkirchen (Saarbrück). By means of sheets they were able to isolate in this gallery, a compartment containing about 700 cubic feet, into which fire-damp taken from the mine was introduced to make an explosive mixture. The composition of this mixture was known by the position of the bell of the gas-holder in which the gas was enclosed.

The explosive cartridges were either laid on the ground or stemmed at the bottom of holes 1 foot 8 inches to 2 feet deep, drilled in blocks of sandstone or coal 2 feet 8 inches to 3 feet 4 inches in length, 2 feet 4 inches to 2 feet 8 inches wide, and 1 foot 8 inches thick. The blocks were covered by a layer of coal-dust from 8 inches to 1 foot thick. The floor of the gallery was covered with coal-dust for from 11 to 22 yards in length.

The explosion of the fire-damp was ascertained by observing, through windows suitably placed, the flame produced at each explosion.

The results obtained by the Prussian Commission have scarcely been consistent, and its conclusions have notably varied as time progressed.

These contradictions, besides those inherent to the subject which have been met with, and the reason of which will be explained further on, seem to be due to several causes, among which the principal are as follow :—

(1) Mixtures were often used, too low in fire-damp and almost non-inflammable (5 to 7 per cent. of fire-damp).

(2) There were no means of knowing for a certainty that the explosive had been fired effectively. It will be seen later that this condition is the most important of all to be known.

Be that as it may, the principal results at which the Commission progressively arrived are as follows :—

Dynamite, which until June of 1885 had, exploding unconfined, only once ignited fire-damp, almost invariably ignited it in the experiments of July in the same year. The Commission attributed this change to the substitution of a dry dynamite, that is to say, one in which the nitro-glycerine is thoroughly absorbed by the silica, for a wet dynamite, from which the nitro-glycerine had some tendency to exude.

Blasting-gelatine (‡) in 1885 had, exploding unconfined, never ignited fire-damp, and had only kindled it once, when tightly stemmed at the bottom of a shot-hole, with a gaseous mixture containing 9 per cent. of fire-damp. In 1887 ignition was effected by unconfined explosion. On the other hand, even with heavy charges (9·88 ounces) a mixture of 10 per cent. of fire-damp was not ignited when the cartridge was stemmed in shot-holes drilled in blocks of sandstone.

Gelatine-Dynamite No. 1 (‖) did not ignite fire-damp in 1885 ; in 1887 it ignited

---

Anlagen zum Haupt-Berichte der Preussischen Schlagwetter Commission.—Vol. IV., p. 63-78.

(†) Zeitschrift für Berg- Hütten- und Salinen Wesen.—Vol. XXXV., p. 271 and 852 (1887).

(‡) Blasting-gelatine consists of a solution of gun-cotton in nitro-glycerine.

(‖) A mixture of 65 per cent. of blasting-gelatine and 35 per cent. of a powder, consisting of saltpetre and of a carbonaceous substance (cellulose).

fire-damp and coal-dust, exploding unconfined. But a charge of 10·58 ounces stemmed at the bottom of a shot-hole did not ignite a 10 per cent. mixture of fire-damp, although under the same conditions an 8·11 ounce charge of powder caused ignition.

Gelatine-Dynamite No. III. (*), which is exploded with difficulty, exploding unconfined, ignited fire-damp in 1885 and 1887.

Compressed Gun-cotton (†) did not ignite fire-damp on detonation either, unconfined or stemmed at the bottom of a hole, either in 1885 or in 1887.

Gun-cotton, mixed with 50 per cent. of nitrate of barium, untried in 1885, had, exploding unconfined, ignited fire-damp in 1887.

Hellhoffite (‡) did not ignite fire-damp in 1885, either exploding unconfined or stemmed at the bottom of a shot-hole. The experiments were not repeated in 1887.

Carbonite (‖) consists of saltpetre, cellulose, and a mixture of nitro-glycerine, with a peculiar sulphurous oil (¶). The inventors have introduced two varieties of this substance. No. 1 ignited coal-dust alone. No. 2 proved thoroughly safe in 42 experiments made with 3·53 oz. cartridges, fired amongst mixtures containing up to 9 per cent. of fire-damp. It was then used on a large scale in the König Colliery for driving three drifts to the coal of the gassy Carlowitz Pit.

Explosions occurred five times in very feebly explosive mixtures of fire-damp and dust; the presence of fire-damp was barely shewn on the benzine lamp, and there was little coal-dust. In four out of these five cases the shots worked well, in the fifth the shot was blown-out, which appears to be not uncommon with carbonite, securite, and roburite. Four of the charges were from 4 to 4½ (3·53 oz.) cartridges; for the blown-out shot and for another of the five shots the charge was only from 2 to 2½ cartridges. Although the four successful shots only caused local explosions, the blown-out shot ignited the coal in place.

Further tests were then made in the experimental gallery, and with 14·11 oz. of carbonite, coal-dust was ignited twice out of five times.

It should be added that the low power of the explosive, which otherwise gave it in working coal a superiority over other blasting explosives, did not permit the employment of small charges in the mine.

Kinetite, of a complex composition, containing chlorate of potash, did not ignite gas. The presence of chlorate of potash makes this substance too dangerous, for its use to be recommended.

As for *Securite*, consisting of dinitro-benzol and nitrate of ammonium in various proportions, with a nitrated resin, and traces of naphthalene and nitrate of soda, two different mixtures had given good enough results in April and May, 1887, but in August the same year a 3·53 oz. cartridge suspended in a 10 per cent. mixture of fire-damp produced explosion twice out of thrice.

Roburite consists of a chlorinated nitrated hydro-carbon and nitrate of ammonium in various proportions :—

(1) Roburite of the old composition, containing picric acid, ignited gas when the cartridge was inclined at 40 degrees.
(2) Torpedo-roburite ignited the mixture containing 5 per cent. of fire-damp.
(3) Mine-roburite I., composed of dinitro-chloro-benzol, and nitrate of ammonium (without picric acid) ignited once.
(4) Mine-roburite II., similar to the last, but containing phenol besides, did not cause ignition, even when the cartridge was inclined at 40 degrees.

(*) Mixture of 25 per cent. blasting-gelatine and 65 per cent. of the same powder as above.

(†) The percentage of nitrogen is not given.

(‡) Mixture of dinitrobenzol and concentrated nitric acid.

(‖) Sir F. Abel (Min. of Proc. of the Inst. of Civil Eng loc. cit.) says that carbonite consists of saltpetre, nitrate of barium, nitro-benzol, and cellulose. He does not admit that it can ensure safety, because its explosion must be accompanied by flame.

[(¶) Sulphuretted benzol.]

Lithotrite, from Demeuse (Aix-la-Chapelle), caused one ignition.

Schultze powder from Messrs. Voltz, Lichtenberg and Co., of Ludwigshafen, did not prove itself safe in a finely divided state. The powder slightly compressed, caused ignition with 8 per cent. of fire-damp. The powder strongly compressed never caused ignition.

The Bornhardt 15 grain detonators did not cause ignition even with 8 per cent. of fire-damp.

Mr. Hugo Lohmann, after having given (in the Zeitschr für Berg- Hütten-und Salinen Wesen) a summary of the experiments of the Commission on the various explosives, concludes with these words :—

"After the experiments just described, the author is of opinion that the use of the actually known blasting explosives, in the presence of fire-damp, and more particularly in workings containing dry coal-dust, is much more dangerous than has hitherto been usually believed, and that the prohibition of the use of powder and analagous explosive substances, would have but an insignificant influence on the number of explosions of fire-damp or coal-dust" (*).

The Prussian Commission did not spend much time in considering the best means of firing the explosive.

Some experiments were made (May-August, 1887) with safety-fuse. The experimental gallery was filled with mixtures of air, coal-dust, and fire-damp, in which the latter varied from 4 per cent. to 6⅔ per cent. One of the ends of the fuse was inserted in a shot-hole, the outer end cut off, and the free end was then ignited inside the gallery. Nothing occurred when the mixture contained only 4 per cent. of fire-damp ; when this proportion was exceeded, an unsteady flame existed for some seconds, very feeble, bluish or yellowish, in the upper parts of the gallery adjacent to the fuse. With 6⅔ per cent. a feeble explosion occurred repeatedly. With 10 per cent. of fire-damp an explosion immediately occurred (†).

The Prussian, like the English Commission, sought to ascertain if it was possible to ensure security by using explosives in any particular method. They only experimented with the water-cartridges previously proposed by Sir F. Abel. 7·05 ounce cartridges of dynamite were placed in the midst of the "Settle water-cartridge" filled with water, and laid on the floor of the gallery. Under these conditions it was impossible to ignite the gas, even with high percentage of fire-damp, and on firing three such cartridges at once. In one experiment, ten 3·53 ounce cartridges of dynamite, each enclosed in its water-cartridge, were fired at once in a 10 per cent. mixture of fire-damp, without igniting the gas.

Ignition of the explosive mixture could only be effected with 2·2 pounds of dynamite, divided into seven water-cartridges laid on the floor of the gallery, and covered with coal-dust.

The Settle water-cartridges are paper bags 1 foot 8 inches in length, 1¼ inches in diameter for ordinary cartridges, 1½ inches diameter for larger cartridges. In order to assure the complete surrounding of the cartridge by water, a wood plug is slipped into the bottom of the bag, and a tamping of clay is placed above the water before closing the mouth of the bag.

(*) Zeitschr für Berg- Hütten und Salinen Wesen, XXXV. ¶ 44, p. 356. The Mining Council of Bonn was doubtless inspired with similar ideas in drawing up the Regulations for Mines, of August 1st, 1887 (in which blasting is prohibited) without distinction of explosives, in all parts of the mine where fire-damp shows in the lamp. It is only where admittedly inflammable coal-dust is found that a distinction is made, and powder is specially prohibited.

(†) The ignition of explosive mixtures of fire-damp by the fuse, under the conditions in which it was placed by the Prussian Commission cannot be doubted. These experiments are only quoted to confirm the lower limit of inflammability of mixtures of air and fire-damp, which had been previously fixed by Messrs. Mallard and Le Chatelier, between 5·6 per cent. and 6 per cent. of fire-damp. Contrary to the opinion of Sir F. Abel, the presence of coal-dust does not lower or only slightly lowers this limit.

The reporter, Mr. Hugo Lohmann, states that the use of water-cartridges with high explosives gives a high degree of safety, although it may not be absolutely safe under all circumstances. He adds, however, that the use of these cartridges entails a long manipulation, and is not economical in coal, on account of the considerable enlargement of the shot-holes which it necessitates.

Moreover, he mentions (from special communications) that explosions have occurred, notwithstanding the use of water-cartridges, in the Derby and Newcastle districts in England. He also quotes an explosion of fire-damp, mentioned by Mr. Joseph Böhm (No. 13, of the Oester: Zeitschr für B. u. H. W., of 1887), which occurred in the sinking of a pit, with a hole 4 feet 4 inches deep, charged with dynamite stemmed with water and fired by electricity.

Lastly, the Commission tried the use of crystallised carbonate of soda in place of water. With a charge of 3·53 ounces of dynamite, there was no explosion; but with three similar cartridges fired simultaneously, there were two explosions.

Mr. Hugo Lohmann attributes the favourable influence of water and of carbonate of soda to the cooling effect produced by a partial volatilisation of the water caused by the temperature of explosion. It will be seen later that this opinion is very questionable, and that, according to the views of Sir F. Abel, under these conditions there is very little probability of the volatilisation of the water of the carbonate of soda. It is possible that the same effect might be produced by replacing the carbonate with an inert substance, such as very finely powdered sand.

In conclusion, Mr. Hugo Lohmann mentions the experiments made by Mr. Muller, managing director of the Rhenish-Westphalian Explosives Company, of Cologne, who proposes to add carbonate of soda to the mixture itself. Trials made on the 31st August, 1887, in the experimental gallery of the Commission, with a mixture of 10 parts of dynamite (77 per cent. of nitro-glycerine) with 7 parts of carbonate of soda gave favourable results. Further trials have proved that the new explosive, to which the name of "wetter-dynamite" has been given, gives satisfactory and economical results in blasting coal, on account of the diminution in its explosive force.

SAXON COMMISSION.

The Saxon Fire-damp Commission (*) made some experiments on the danger of explosives in the presence of fire-damp. These experiments, besides being few in number, have not elicited anything new.

AUSTRIAN COMMISSION.

The results of the Austrian Fire-damp Commission are not yet known. However, Mr. Johann Meyer, gives some information on this subject in a very interesting report on a competition for a prize of £475, generously offered by coalowners of the Ostrau-Karwin district to "the discoverer of a process to supersede blasting in fiery mines, or to render it safe."

According to Mr. Meyer, the local committee of the Ostrau-Karwin coalfield has ascertained that hellhoffite and blasting gelatine stemmed at the bottom of a shot-hole did not ignite a mixture containing as much as 10 per cent. of fire-damp, and that it is even sufficient to cover these explosives with from 2 inches to 2½ inches of sand to prevent the ignition of fire-damp.

With powder, ignition of gas occurred even when the hole was stemmed, and did not blow out, and the more so with the same covering of sand which made the high explosives safe.

(*) Uebersicht über die Thätigkeit der Commission zur Revision der bergpolizeilichen Vorschriften in Sachsen—Jahrbuch für das Berg und Hüttenwesen im Königreiche Sachsen (1886).

On the other hand, cartridges, exploding unconfined, of blasting-gelatine or hellhoffite (*) have ignited explosive gaseous mixtures at every shot.

These results prove, says Mr. Meyer, that "when an explosive is fired unconfined the possibility of the ignition of fire-damp or of coal-dust can never be avoided."

It is to be noted that the conclusions of the Prussian Commission and those of Mr. Meyer, would (after numerous contradictory experiments) lead one to the result which had *a priori* been foreseen by the French Explosive Substances Commission in its report of 2nd December, 1880.

Mr. Meyer, however, questions the very pessimistic conclusion of Mr. Lohmann, which has been previously quoted. He remarks that shots fired with high explosives blow out but seldom, and that when they are not blown-out they ignite neither explosive mixtures, nor dusts, although shots fired with powder can ignite both, even without being blown out. This proves the great advantages gained by the substitution of high explosives for powder.

Mr. Meyer points out the grave danger which is incurred by the use of fuse in firing shots. Blasting in places where fire-damp can be detected is, it is true, forbidden ; but the safety of the mine then depends on the observance, impossible to ensure, of a rule often actually broken. Mr. Meyer goes so far as to attribute two-thirds of the accidents from fire-damp to the employment of fuse.

He, moreover, remarks that the use of electricity may become dangerous with the sparks from high-tension electricity ; he considers its use (doubtless with exaggeration) as impossible in mines.

After this, it will be no cause of surprise that the jury have awarded a large portion of the proposed prize to Lieut.-Col. Lauer, the inventor of a friction detonator, placed in the cartridge, and fired by means of a wire passing through a tube embedded in the stemming.

According to Mr. Meyer, Col. Lauer's process is at present in exclusive use in several mines in the Ostrau coalfield ; it can be used in all cases, even with the water stemming, and its cost is very slightly above that of ordinary fuse.

There is nothing requiring further note in Mr. Meyer's interesting report, except some information on wetter-dynamite which has been tested in several mines, from an economical point of view. It was ascertained that this explosive is difficult to fire, and as regards its useful effect did not give absolutely satisfactory results.

Such are nearly all the facts known at present relative to the subject matter of this Commission. Many of them were published during the course of these researches, and some even after their completion.

ACTION OF COAL-DUST.

The Prussian Commission gave much attention to the part played by dusts, either alone, or in combination with fire-damp. Two members of the Sub-Commission (†) have already studied the Prussian experiments from this point of view, and have shown that they seem rather to confirm the opinion, which they had already upheld and supported by independent researches, namely, that coal-dust only plays a subordinate part in mine explosions. Sir F. Abel, in a recent paper,

---

(*) Mr. Margraf, in an article published in the Zeitschrift fur das Berg, Hutten und Salinenwesen in Preussischen Staate (Vol. XXXIV. 1886), announced that he had not been able to ignite explosive mixtures with hellhoffite. Further experiments not yet published have, according to Mr. Meyer, led Mr. Margraf to conclude that non-protected cartridges of hellhoffite ignite explosive mixtures. Mr. Sharizér, of Rossitz, is said to have even ignited coal-dust with this explosive.

(†) MM. Mallard and Le Chatelier, "On the work of the Prussian Fire-damp Commission." Ann. des Mines, 8th series. Vol. IX., p. 338 (1886).

before the London Institute of Civil Engineers, has just given the support of his high authority to this opinion (*).

The inflammability of mixtures of air and coal-dust is, moreover, far inferior to those of air and fire-damp, and it is universally agreed that similar mixtures can only be ignited by the influence of intensely hot flame. It is, therefore, very evident that an explosive considered sufficiently safe in the most explosive mixtures of air and fire-damp will, *a fortiori*, be perfectly safe in the presence of mixtures of air and dust.

It has, therefore, been considered a complication of slight value in the experiments, to place coal-dust in a state of suspension in the gaseous mixture.

Some experiments, however, were made with dusts, and are quoted here to avoid further repetition.

It was ascertained that dynamite exploding unconfined, in the presence of coal-dust (very fine and very inflammable) (†), did not ignite these dusts.

Dynamite, burning without explosion, did, on the contrary, ignite the dust, as has been shewn, by placing a charge of 772 grains of dynamite in a cylindrical hole drilled in a block of wood, covered with coal-dust, the dynamite being ignited with a Bickford fuse without a detonator.

A dynamite charge of 772 grains placed in a tin tube ·98 inch internal diameter, and 1·57 inch external diameter, stemmed five inches deep with very fine coal-dust, did not ignite fire-damp.

COMMISSION APPOINTED BY THE MINISTER OF PUBLIC WORKS.

In consequence of the publication of the first series of experiments made by the Prussian Commission, which seemed to attribute an almost complete safety to the use of certain explosives, the Minister of Public Works appointed, on the 12th February, 1887, a Commission (‡), charged with the study of questions relative to the use of explosives in fiery mines.

From its earliest sittings, this Commission considered it necessary to repeat the experiments of the Prussian Commission. After a consultation between the Ministers of War and Public Works, it was decided that the Explosive Substances Commission, appointed by the Minister of War, should be charged with this experimental investigation. Messrs. Mallard, Aguillon, and Le Chatelier were temporarily attached for this purpose.

The Explosive Substances Commission, at its sitting of 31st March, 1887, nominated a Sub-Commission, whose names have already been given, to proceed with the necessary researches.

Since the 4th April, this Sub-Commission settled the programme of experiments, which were continued without interruption, and the results of which are about to be made known.

(*) The Institution of Civil Engineers, Minutes of Proceedings, 24th May, 1887, p. 167 and following. These are the words of Sir F. Abel alluded to—"Mr. Bedlington had, in the author's opinion, expressed the rational view with regard to the coal-dust question, when he stated that, while he was not convinced that dust alone would serve to account for explosions of magnitude, which should be of very much more frequent occurrence if such were the case, he admitted that, where much dust was present, explosions were greatly aggravated thereby."

(†) Blanzy coal-dust was used, which two of the members of the Sub-Commission, Messrs. Mallard and Le Chatelier, had used in the experiments made for the French Fire-damp Commission.—Ann. des Mines, 8th series, p. 5 (1882).

(‡) This Commission consists of M. Haton de la Goupillière, Inspector-General of Mines (President); Sarrau, Engineer-in-Chief of Explosives; Mallard, Inspector-General of Mines; Lorieux, Inspector-General of Mines; Aguillon, Inspector-General of Mines; Le Chatelier, Engineer of Mines (Secretary).

CHAPTER I.

DESCRIPTION OF THE APPARATUS AND METHODS OF EXPERIMENTING.

The experiments would have had little interest, if they had been a repetition of the researches of the Prussian Commission, which were made as nearly as practicable under actual working conditions.

It was determined to conduct the observations under conditions as exactly defined as possible, and to carry on the researches as a scientific investigation.

It was hoped thus to account for the anomalies noted in the Prussian experiments, and even to be able to formulate laws whose results would be immediately applicable in practice.

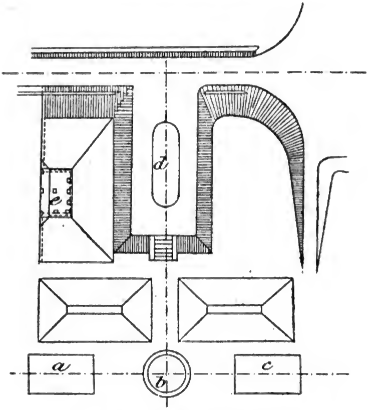


Figure 1.—Ground plan. Scale 1 : 400.
a—Apparatus for generating marsh gas.
b—Gasometer.
c—Belleville steam boiler.
d—Experimental boiler.
e—Shelter for the experimenters.

Not possessing a natural source of fire-damp, recourse was had to marsh gas, artificially made, and the most convenient process was employed that is to say, the action of heat on a mixture of acetate of soda and soda lime (*)

It was intended to fire the explosives in a closed vessel, so as to be able to make an exact measurement of the amount of fire-damp mixed with air, to be able to study completely the conditions of the detonation of the explosives, and to be always well assured of the ignition or non-ignition of the gaseous mixture. To fulfil these conditions, a steam boiler of about 350 cubic feet capacity was chosen.

(*) Soda lime is lime slacked with a solution of causti soda.

The apparatus was erected at the Sevran-Livry Powder Mill, under the superintendence of Mr. Lambert, director of the works, and Mr. Bruneau, engineer of explosives. It is shown in a general way in Figure 1. It comprises:—

(1) An apparatus for generating marsh gas (*a*).
(2) A gasometer intended for the collection of the manufactured gas (*b*).
(3) A small Belleville steam boiler used to raise the steam to work an ejector (*c*).
(4) An iron boiler, tested to 8½ atmospheres, provided with an ejector (*d*).
(5) A shelter for the experimenters (*e*).

Apparatus for generating Marsh Gas.—The apparatus used for the generation of the marsh gas was kindly supplied by the balloon depôt at Meudon; it had been designed and used there for the generation of hydrogen intended to inflate balloons. It consists of ten iron tubes or retorts, 7 feet 8½ inches long (see Figure 2), fitted with cast iron plugs at one extremity, and at the other with a screwed extension of less diameter than the body of the cylindrical tube. These retorts placed in two horizontal ranges above a fire-grate, are held in position by means of three plates, pierced with holes, fixed in the side walls of the furnace.

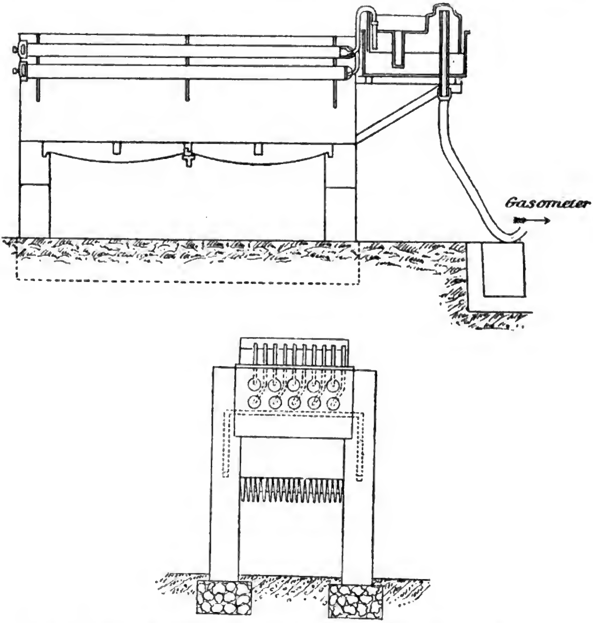


Figure 2.—Elevation and section of the apparatus used for generating marsh gas. Scale 1 : 40.

At the end of the furnace is a receiver, to the bottom of which curved tubes penetrate, connected with the retorts by screwed joints; lastly, a pipe 2·36 inches diameter traverses the receiver, ending at the dome, and connects it with the little gasometer.

The charging of this apparatus is effected by introducing into the retorts semi-cylindrical troughs, in which the mixture of acetate of soda and caustic soda and lime has been previously placed. Each charge consisted of about 4½ lbs. of the powdered mixture.

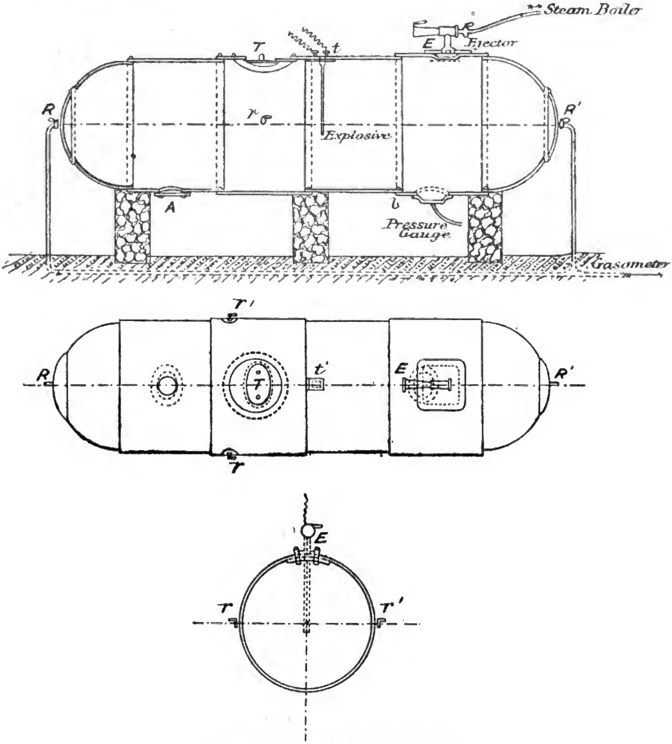


Figure 3.—Plan and sections of the boiler.

The retorts being charged, a wood-fire is kindled, which is slowly fed, the fuel being distributed uniformly over the whole surface of the grate. The gases, having passed through the water contained in the receiver, are conveyed to the small gasometer *b*.

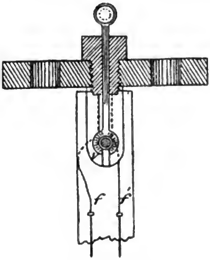
Experimental Boiler.—The boiler employed for the experiments (Figure 3) measures externally 18 feet 5½ inches in length, and 4 feet 11 inches in diameter; the thickness of the plates is ·63 inch on the cylindrical part, and ·55 inch on the egg ends; its internal capacity, exclusive of the reservoir for the transmission of pressure to the pressure gauge, is 359·2 cubic feet.

The boiler is provided on its upper part with an elliptical manhole *T*, 1 foot 1·78 inches by 1 foot 5·72 inches; with a rectangular hole *t* placed in the middle of the length, measuring 3·94 inches by 1·97 inches for the insertion of charges, and with a hole *E*, 3·94 inches internal diameter on which the steam ejector is fixed.

On the lower part, at one end, is a circular hole *A* 1·97 inches diameter for filling the boiler with air, and at the other end is a flanged-plate *b* for the purpose of attaching the lead pipe which connects it with the pressure gauge (*).

On the horizontal section, passing through the axis, are 4 cocks ·39 inch diameter, and two brass plugs. The two cocks *R*, *R'*, one at each end of the boiler, are connected with the gasometer; a third lateral one *r* is connected with a tube dipping into water, which permits the measuring of the vacuum obtained by the action of the ejector; lastly, a fourth lateral cock *r'* is connected with a water-gauge formed by a U-tube.

One of the brass plugs is provided with two insulated copper wires, which allow either a spark to pass into the gaseous mixture, or raise a fine iron wire to red heat.



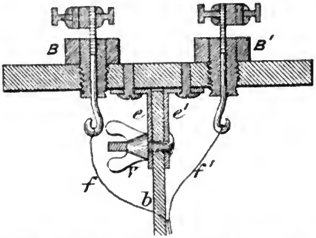
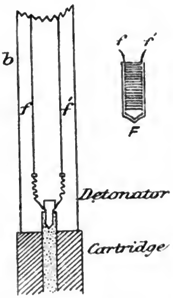


Figure 4.—Details of the attachment of the cartridge to the lid of the small hole of the boiler.



The cartridges of the various explosives to be tested are introduced through the rectangular hole in the upper part of the boiler. They can also be introduced through the manhole if their diameter is too great; it is seldom necessary to use this means, which prolongs the operation.

Electricity is generally used to fire the explosives. For this purpose the lid of the small hole is provided with two screwed plugs of lignum-vitæ *B* and *B'* (Fig. 4) which pass through it. Through the axis of each of these a copper rod passes, which is also screwed, projecting outside, and terminated by a hook at the inner end. Lastly, in the centre of the lid are fixed two small copper angle plates *e*, *e'*, the open arms of which are clamped by a

---

(*) This pressure gauge, found to be useless, was abandoned after the first experiments.

pressure screw *V*, which holds fast a wooden rod *b*, 2 feet 5·53 inches long, at the extremity of which the explosive under experiment is attached. These deal rods 1·18 inch by ·2 inch in section are fitted with copper wires *f*, *f'*, connecting the detonator with the hooks of the lid, thus forming a closed circuit.

Gasometer.—The gasometer measures 9 feet 2½ inches in diameter, and 3 feet 3½ inches in height, giving it a capacity of about 217 cubic feet.

Boiler and Ejector.—The steam boiler used to work the ejector is a portable Belleville of 12 horse-power; a cock placed on the steam pipe drives the ejector by a current of steam of from 10 to 12 atmospheres pressure; this last apparatus will produce a vacuum of six inches of water-gauge in one or two minutes.

MODE OF CARRYING OUT AN EXPERIMENT.

The boiler was well aired before carrying out an experiment. The plate which closes the hole *A* in the bottom was raised; steam was turned on to the ejector and allowed to work for 7 or 8 minutes; all the other openings in the boiler being closed, a current of air traversed the boiler from one end to the other, and upwards from the bottom. This operation being completed, all the apertures were closed, and the explosive to be tested was introduced.

The cartridge, fixed on the wooden rod, was fitted with a detonator, which could be fired by an electric current; the copper wires of the rod were connected with those of the detonator, and with the hooks of the copper rods which pass through the wooden plugs in the lid; to fire the explosive, it was, therefore, necessary to fix the wires of the battery to the ends of the copper rods, which project above the lid, and to close the circuit.

This method allows the explosives to be tested, to be fixed beforehand on the rods; it is then only necessary to fix the rod between the two angle plates by means of the pressure screw, and to fasten the wires on the hooks. This operation can be quickly performed. The lid being in position, the cartridge will be in the axis of the boiler, and in the centre line.

The joints being closed, the ejector is worked and the water rises in the glass tube connected with the boiler by india-rubber tubing.

When the vacuum is seen to be sufficient, the cover of the ejector is closed, being previously coated with white lead, so as to obtain an hermetical joint, and to be assured, by the steadiness of the water-gauge, that the boiler shows no leak.

This observation made, the boiler is placed in communication with the small gasometer, and the two cocks placed at the ends of the boiler are simultaneously opened to allow of the entrance of the fire-damp; the gradual descent of the water in the gauge is observed till the desired proportions of air and fire-damp are indicated.

The gas penetrating into the rarefied air, with a speed of many yards per second, produces a first mixing, increased by the re-entry of air from the same points after shutting off the connection with the gasometer. This re-entry of air is effected by opening the cocks placed at the ends of the boiler.

The atmospheric pressure being restored in the interior of the boiler, all the cocks are shut, and the ejector flange is replaced by a solid cap.

An experiment can now be made; the composition of the gaseous mixture is then obtained, by deduction, from the volume of gas used.

The conducting wires are attached to the little rods in the lid, by which the explosives are introduced and the circuit is closed. When the explosive tested, causes ignition of the gaseous mixture, it is indicated by the heating of the boiler plates, as well as by the considerable pressure which immediately follows the ignition of the air and fire-damp, and which is followed by a depression when the water vapour is condensed.

It was intended that the pressures should be registered by means of a recording pressure gauge, analogous to that which had been used in the experiments of Messrs. Mallard and Le Chatelier on explosive gaseous mixtures; but the readings of the gauge being unreliable and delaying the experiments, its use was given up.

DESCRIPTION OF GAS USED.

The combustible gas produced in the retorts and stored in the gasometer, was analysed as follows :—

	Per cent.
Air	10·8
Gases absorbed by bromine	7·9
Carbonic acid gas	0·0
Fire-damp, by difference	81·3

No tests were made for hydrogen.

A second analysis gave nearly the same result.

The presence of the air is explained by the fact that, for economical reasons, the gas produced during the first period of heating was used, and which brought over with it the air with which the retorts were filled at the commencement.

Except for this quantity of air, which must be taken into account in the preparation of the mixture introduced into the boiler, the gas is almost pure marsh gas and should have almost the same properties.

The combustibility, it is true, should be a little increased by the presence of the higher hydro-carbons, which are absorbed by bromine, but this increase cannot be considered as very material. Indeed, the speed of propagation of ignition in a tube is sensibly the same for this gas, as that previously determined by Messrs. Mallard and Le Chatelier for fire-damp.

Besides, it appeared possible that natural fire-damp contains a notable quantity of hydro-carbons absorbable by bromine, and it seemed advantageous, as regards the accuracy of the conclusions, that the gas used should be a little more combustible than that found in practice.

Nearly the whole of the experiments have been made with a mixture formed by introducing into the boiler a volume of gas producing a pressure of 46·46 inches in the water-gauge. With gas containing about 10 per cent of air, the mixture thus formed, contains about 10·3 per cent. of marsh gas. This is nearly the most explosive mixture.

The mixture formed by the introduction of a volume of gas, corresponding to a pressure of 27·56 inches of water, or a proportion of 6·1 per cent. of marsh gas, developed in burning a feeble pressure, and was near the lower limit of ignition.

As regards facility of ignition by explosives, no marked differences were found between mixtures containing from 12·5 per cent. to 6·1 per cent. of gas. This is in accordance with the fact, ascertained by Messrs. Mallard and Le Chatelier, for hydrogen and carbon monoxide, that the temperatures of ignition of mixtures that these gases form with oxygen, do not materially vary with the introduction of other gases, notably of excess of nitrogen and oxygen.

CHAPTER II.

EXPLOSIVES SUSPENDED IN THE MIDST OF GASEOUS MIXTURES.

THIS chapter describes the experiments made with explosives freely suspended, without covering, in the midst of gaseous mixtures.

The third chapter is devoted to experiments made by placing the explosive in a closed vessel.

The fourth chapter describes experiments on detonators.

A fifth and last chapter is devoted to conclusions.

The appendices contain a summarised table of the experiments, and two notes, purely theoretical, written by Messrs. Mallard and Le Chatelier.

I.—DETONATORS.

The question of detonators are considered in a special chapter. It is sufficient to state here that plugged caps of from 23 to 31 grains of fulminate of mercury do not ignite explosive mixtures, although plugged caps of 77 grains do ignite them.

Plugged caps of 23 grains were almost constantly used alone, or associated in varying numbers. The detonation was caused by a wire raised to red heat by an electric current.

II.—EXPLOSIVES ALREADY KNOWN.

Experiments have been made with the following explosives already known and used :

(1) Ordinary blasting powder.

(2) Military gun-cotton, containing nitrogen corresponding to the production of ·81 cubic inch of NO_2 per grain of material, in an analysis by the Schloesing process ; strongly compressed into cubes of 432 grains.

(3) Mining gun-cotton, containing nitrogen corresponding to ·76 cubic inch of NO_2 per grain of material ; strongly compressed into cylindrical cartridges of 463 grains.

(4) Gun-cotton, still less nitrogenous, equal to ·68 cubic inch of NO_2 per grain, in compressed cartridges of 772 grains.

(5) Dynamite No. 1 of Vonges, containing 25 per cent. of randanite (*)

(6) Dynamite No. 0 of Paulilles.

(7) Ammonia-dynamite of Paulilles.

(8) Blasting-gelatine of Paulilles.

(9) Gelatine-dynamite of Paulilles.

All these dynamites are in cartridges of 772 grains.

(10) Favier explosive.

(11) Hellhoffite.

(12) Pyroxiline powder from Moulin-Blanc, similar to Schultze powder, containing gun-cotton and nitrate of barium, in strongly compressed cartridges of 772 grains.

(13) A powder, of similar composition, made at the Belgian Powder Mills at Wetteren.

(14) An explosive, again of similar composition, formed by a mixture of gun-cotton and nitrate of barium.

(15) Bellite, recently introduced by Mr. Lamm.

[(*) Randanite is a silicious material, similar to kieselguhr, found in the neighbourhood of Ceyssat north of France, it is supposed to be felspar decomposed by the action of natural mineral waters.]

Blasting Powder.—The ease with which the deflagration of ordinary powder ignites fire-damp is so well known that it seemed of little use to make experiments on that point.

It has been proved that a cartridge of 463 grains of powder suspended in the middle of a kind of cylindrical bag of impermeable paper filled with water (the Settle cartridge) has ignited fire-damp on explosion. The numerous devices proposed at different times to avoid the danger of powder in fiery mines, by tamping with water, thus appear condemned in a decisive manner.

Dynamite (*No. 1 Vonges and No. 0 Paulilles*).—The No. 1 dynamite from Vonges and the No. 0 dynamite from Paulilles consist of a mixture of 75 per cent. of nitro-glycerine, and of 25 per cent. of silicious earth. They behave in an identical manner. These explosives, when unconfined, are easily fired by the use of one plugged cap of 23 grains of fulminate, and ignite the gaseous mixture in which the cartridge is suspended. All the very numerous experiments have given the same result.

Besides, it has been ascertained that a cartridge of 772 grains of dynamite, placed in the midst of a Settle cartridge filled with water ignited fire-damp once out of two trials.

Ammonia-Dynamite of Paulilles.—Ammonia-dynamite is a mixture in various proportions, of nitro-glycerine, nitrate of ammonium, and of carbonaceous matter, intended to use up, in burning, the excess of oxygen produced by the detonation of the dynamite and that of the nitrate.

The Paulilles ammonia-dynamite, on detonation, ignited the gas mixture, when the proportion of fire-damp was above 6·1 per cent., that is to say, when it became clearly inflammable.

Gun-cotton.—Military gun-cotton (equal to ·81 cubic inch NO_2 per grain) (*) enclosed in the very thin brass cases common in army service, ignited fire-damp once out of three experiments.

Mining gun-cotton (equal to ·76 cubic inch NO_2 per grain) (†) a little less strongly compressed than military gun-cotton, and without a case, ignited the gaseous mixture ten times in ten tests, both with the larger (12·8 per cent.) as well as the smaller (5·7 per cent.) proportions of fire-damp.

Gun-cotton (equal to ·68 cubic inch NO_2 per grain) (‡), strongly compressed, and without a case, fired by the action of two detonators of 23 grains of fulminate, ignited the gaseous mixture in the one experiment which was made.

Blasting-Gelatine and Gelatine-Dynamite.—Blasting-gelatine is a solution of gun-cotton in nitro-glycerine, forming a sort of gum or rather gelatine. The gun-cotton, only in small proportion, should be just sufficient to be completely burnt by the excess of oxygen of the dynamite.

Gelatine-dynamite, of much more variable composition, is formed of blasting-gelatine with the addition of a dual mixture such as nitrate of potash or of soda, and charcoal or sawdust.

In warm weather, such as is experienced in France in May, these explosives are fired easily. During winter their explosion has almost always been incomplete if not *nil*, with caps of 23 grains, and with gelatine-dynamite even of 46 grains of fulminate.

(*) [If cellulose be represented by the formula $C_{24} H_{40} O_{20}$, the various nitrates obtained by treatment with sulphuric acid and nitric acid may be represented as formed from cellulose, by replacement of hydrogen by the group NO_2, consequently military gun-cotton] corresponds very nearly to decanitric cellulose $C_{24} H_{30} (NO_2)_{10} O_{20}$.

(†) This corresponds nearly to nononitric cellulose $C_{24} H_{31} (NO_2)_9 O_{20}$.

(‡) This corresponds nearly to octonitric cellulose $C_{24} H_{32} (NO_2)_8 O_{20}$.

This incomplete explosion can be very simply observed by noting the compression produced in the boiler by the firing of the cartridge, when the boiler was filled with air or when, filled with a gaseous mixture, which was not ignited by the explosive. It is certain that when the gaseous mixture was not ignited, the explosion of the blasting-gelatine or the gelatine-dynamite did not cause a higher pressure than a few inches of water. The firing of the detonator did not produce a sensible pressure, the cartridge detonated therefore, but only in a very partial manner, and under these conditions did not ignite the gas.

By increasing the power of the detonator the ignition of gas with blasting-gelatine and gelatine-dynamite was ensured.

It may be said that blasting-gelatine and gelatine-dynamite ignite fire-damp, in which they are suspended, every time that they explode, more or less completely.

These facts have induced the careful study of the method of firing explosives, unconfined. The researches on this matter are recorded subsequently.

Hellhoffite.—Hellhoffite has not been exploded unconfined. This explosive is said to be composed of dinitro-benzol, mixed with 1½ to 2½ times its weight of nitric acid. The mixture is made just before using, which appears to be an obstacle to its customary employment in mines.

Favier Explosive.—Mr. Favier's explosive, as introduced by him to the Explosive Substances Commission, is essentially composed of a mixture of 9 per cent. of mononitronaphthalene and of 91 per cent. of nitrate of ammonia, so that the nitronaphthalene exactly utilises, in burning, the excess oxygen in the nitrate. The two substances are intimately mixed and very strongly compressed. A cylindrical hole, in the middle of the cartridge weighing 849 grains contains 77 grains of powdered material, which acts as an intermediate detonator, and is principally composed of gun-cotton and nitro-glycerine.

The Favier explosive does not explode unconfined. This is rather an advantage than an inconvenience, if there was a certainty of its detonation when it is stemmed in a shot-hole, and if under these conditions there was no fear of missed shots. Experiments made in the mine can alone solve this question. Stemmed in metallic tubes, in a manner which will be described further on, this explosive was only detonated very incompletely, even with 77 grains of fulminate.

It happened once, out of two tests, that the gaseous mixture was ignited by detonation with three plugged caps of 23 grains fulminate, not of the Favier explosive itself in its compressed state, but the material of the explosive reduced to a fine powder.

It is desirable that new trials should be made upon this substance which, on account of the similarity with the explosive proper, should not be condemned without further consideration, as regards safety.

In any case, it would be necessary to modify the nature of the intermediate detonator, which, in itself, appears liable to ignite gaseous mixtures.

Bellite.—Bellite, recently introduced by Mr. Lamm, should be, according to the inventor, composed of 80 parts of nitrate of ammonia and 20 parts of dinitro-benzol.

This explosive, as shewn later, is completely detonated when confined.

Unconfined, it fires incompletely with a detonator of 19 grains of fulminate. Its detonation is still incomplete, although more marked, with 46 grains of fulminate.

Two tests were made under these last conditions, on a warm moist day, without causing ignition of fire-damp.

The composition of bellite, as stated by Mr. Lamm, does not seem to be exact. Experiments made with a bomb have, indeed, at a charging density of ·3, shown a pressure of about 181 foot-pounds, whilst the theoretical pressure (according to the calculations shewn subsequently) should be, at that density, about 239 foot-pounds.

The mixture of 20 parts of dinitro-benzol and 80 parts of nitrate of ammonia gave, under the same conditions, a pressure of 275 foot-pounds, which more nearly approximates to the theoretical figure, but which is considerably more than that obtained with bellite.

A cartridge of 772 grains, made with this mixture, did not ignite the gaseous mixture in the midst of which it was exploded (1 test).

Gun-cotton with Nitrate of Barium.—A powder manufactured some years ago at the Moulin-Blanc Powder Mill, and which was found in the magazines at Sevran, was tested. According to the analysis of Mr. Bruneau, it consists of

	Per Cent.
Nitrate of barium	42·6
Gun-cotton	57·4

A cartridge of this substance, exploding in a gaseous mixture, ignited it.

A nitrated cotton from the Wetteren Powder Mill (Belgium), which is also a mixture of gun-cotton and nitrate of barium, also ignited the gas.

Pyroxyline Powder from Moulin-Blanc.—The pyroxyline powder manufactured at the Moulin-Blanc Powder Mill is a mixture composed of—

	Per Cent.
Nitro-cellulose (equal to ·69 to ·73 cubic inches NO_2 per grain)	60
Nitrate of barium	30
Saltpetre	6
Bone-gelatine	3
Paraffin	1

This substance, which is sold to the public as a granular powder, has been used in these experiments in the shape of prismatic cartridges, very strongly compressed, and coated with paraffin. It explodes easily when unconfined with a detonator of 23 grains of fulminate.

In the fourteen experiments which were made with this substance, suspended in the midst of a gaseous mixture, it only twice happened that the detonation of the explosive caused the ignition of the gas.

These two experiments were made on a very warm and sultry day, that is to say, very humid; the boiler, strongly heated by the sun, being burning hot on the outside, and the internal temperature exceeding 104 degs. F. On account of these atmospherical conditions, these two experiments should be considered as somewhat abnormal. This point will be considered hereafter.

III.—STUDY OF NEW EXPLOSIVES, NOT IGNITING FIRE-DAMP.

The example of the pyroxyline powder showed that it was possible to find an explosive which, fired without an envelope, did not ignite gaseous mixtures. The manufacture of similar explosives might be examined so as to establish the general conditions which should be fulfilled.

Dynamite and Soda Crystals.—As has been seen in the historical introduction, a Prussian Explosive Manufacturing Company has tried a mixture of dynamite with powdered soda crystals.

An intimate mixture of No. 1 Vonges dynamite with soda crystals, very finely powdered, does not ignite fire-damp, exploding without envelope, when the mixture of the two substances is made with equal weights of both substances (3 tests).

Dynamite and Crystallised Sulphate of Soda.—The carbonate of soda was replaced by crystallised sulphate of soda, with 10 equivalents of water.(*) It was ascertained that the mixture of dynamite and sulphate of soda, in equal parts does not ignite fire-damp (1 test), although the mixture containing two parts of dynamite to one part of sulphate does ignite it (1 test).

Dynamite and Ammonia-alum.—The sulphate and carbonate of soda are not only efflorescent, but are also liable to become deliquescent under atmospheric conditions which may occur in mines; they may, however, be replaced by a very hydrated salt, very stable, and having the advantage of being almost completely volatilised when decomposed at a high temperature, viz., ammonia-alum.(†)

A mixture of dynamite and alum in equal weights did not ignite gas (2 tests).

A mixture of two parts of dynamite and one part of alum ignited the fire-damp only once out of three tests; a mixture of four parts of dynamite and one part of alum ignited it (1 test).

Dynamite and Sal-Ammoniac.—If, in the preceding mixtures, the substances added to the dynamite act by absorbing a part of the heat of explosion in the volatilisation of water, the use of a hydrated salt is not indispensable to procure the same result. It suffices that the salt be susceptible of decomposition at high temperature, thus absorbing heat; and it is an advantage, as regards the useful effect of the mixture, that the products of decomposition should be gaseous.

Sal-ammoniac was considered, which is very stable at ordinary temperatures, and is decomposed wholly into gases only at high temperature. For such purposes the sal-ammoniac should be very finely powdered (which is rather difficult) and very intimately mixed.

With mixtures containing 67 per cent. of dynamite and 33 per cent. of sal-ammoniac the gas was ignited.

With mixtures of 60 per cent. of dynamite, with 40 per cent. of sal-ammoniac, ignition occurred only once out of three experiments.

With mixtures in equal weights, there was no ignition of gas (3 experiments).

Dynamite and Coal-Dust.—Most varieties of coal freely give off volatile products when raised to a not very high temperature. It was, therefore, permissible to suppose that mixtures of coal-dust and dynamite might produce the same effect as the mixtures described above.

Dust of three kinds from different coals were supplied. One, from Blanzy gave, on calcination in a closed vessel, 40 per cent. of volatile matter; the second from Drocourt (Pas-de-Calais), contained 27·86 per cent. of volatile matter; lastly, the third from Dourges (Pas-de-Calais) contained 23·6 per cent. of volatile matter.

Mixtures containing one part of dynamite and one part of Blanzy coal-dust (2 experiments), two parts of dynamite and one part of coal-dust (1 experiment), and even four parts of dynamite to one part of dust (1 experiment) did not ignite the fire-damp.

With equal weights there was no ignition, either with the Drocourt (1 experiment) or the Dourges coal-dust (1 experiment).

[(*) Glauber's salts, $Na_2\ SO_4 + 10\ H_2\ O$.]

[(†) Ammonia-alum, $(NH_4)_2\ SO_4$, $Al_2\ (SO_4)_3 + 24\ H_2O$, would leave $Al_2\ O_3$ as solid residue.

These experiments are interesting, but there is not much prospect of finding in mixtures of dynamite and coal-dust an explosive showing any security; for, in spite of the results of the experiments, it seems possible that with coal a little more inflammable, or under peculiar circumstances, difficult to define, the coal-dust raised to a high temperature may burn in the air. The result obtained with lignite renders this reservation necessary.

Dynamite and Lignite Dust (*Brown Coal*).—Lignite yields a still larger proportion of volatile matters than coal.

A brown lignite, coming from Germany, powdered under rollers at the Sevran Powder Mill was used, containing 62·4 per cent. of volatile matter.

A mixture of two parts of dynamite and one part of lignite ignited fire-damp.

This result, though apparently contradictory to the former, is easily accounted for, if it be considered that not only is lignite much more inflammable than coal, but also that on distillation, a kind of charcoal, inflammable at a low temperature, is produced.

Dynamite and Nitrate of Ammonia.—Guided by the theoretical reasons, subsequently explained, experiments were made with mixtures of dynamite and nitrate of ammonia. These mixtures differ, however, from those which are known under the name of ammonia dynamite, in that, not desiring to increase the mechanical effect of the explosive, the excess of oxygen in the dynamite and in the nitrate was not utilised by the addition of a carbonaceous substance.

An intimate mixture of 20 per cent. of dynamite (No. 1. Vonges) and of 80 per cent. of nitrate, exploded unconfined, in two experiments did not ignite the gaseous mixture.

Nitrate of ammonia does not play here altogether the same rôle as substances like sal-ammoniac, because it is itself an explosive, and gives off heat in decomposing into nitrous oxide (N_2O) and water (H_2O). But it gives off less than dynamite, and the explosive effect of the mixture is consequently diminished. The theory of these phenomena, will be hereafter considered.

Gun-cotton and Sal-Ammoniac.—Gun-cotton has been mixed with various substances. This mixing is most difficult; and was effected under the lightest stones at the powder mill.

The first experiments were made with mixtures of mine gun-cotton with sal-ammoniac.

A mixture of 80 per cent. of mine cotton with 20 per cent. of sal-ammoniac did not ignite fire-damp (1 experiment only), but a mixture of 75 per cent. of cotton and 25 per cent. of sal-ammoniac did ignite it. It would be necessary in order to ensure a sufficient degree of security to increase the proportion of sal-ammoniac, but in doing so a non-explosive point is soon reached. Similar mixtures were, therefore, given up.

Gun-cotton and Nitrate of Ammonia.—Mixtures of cotton and nitrate of ammonia were next tried. Messrs. Sarrau and Vieille have made an exhaustive study of a mixture containing 60 per cent. of endecanitric cotton, (*) and 40 per cent. of nitrate of ammonia, in which the oxygen of the nitrate suffices, with a very small excess, to complete the combustion of the cotton.

Cartridges manufactured with this composition, some years ago at Moulin-Blanc, do not explode or explode imperfectly. New cartridges were made at Sevran, by employing either military gun-cotton (= ·81 cubic inch, NO_2 per grain), or a much less nitrated cotton (= ·68 cubic inch, NO_2 per grain).

[(*) Endecanitric gun-cotton may be represented by $C_{24}\ H_{29}\ (NO_2)_{11}\ O_{20}$.

Cartridges containing 30 parts of military cotton and 70 parts of nitrate have ignited fire-damp twice out of thrice.

Cartridges containing 20 per cent. of military cotton and 80 per cent. of nitrate, have ignited fire-damp once out of twice.

A cartridge containing 35 per cent. of cotton (·68 cubic inch, NO_2 per grain), and 65 per cent. of nitrate ignited the fire-damp.

Cartridges containing 20 per cent. of cotton (·68) and 80 per cent. of nitrate did not ignite the gas. In seven experiments the detonation was effected easily enough in all of them, with two caps of 23 grains of fulminate.

It appears, therefore, that cartridges containing 20 per cent. of lowly nitrated cotton, are practically secure. It is possible that security will be still better ensured, without compromising the completeness of the detonation, at least when confined, by still further diminishing the proportion of cotton.

Lastly, it is clearly evident from the experiments that it is possible, by mixing an explosive with substances which are non-explosive in themselves, or which produce a smaller explosive effect than the explosive itself, to diminish their power, and thus to manufacture dual explosives which, while producing sufficient mechanical effects, do not cause, at least in the majority of cases, fired without envelope, the ignition of the gaseous mixtures which surround them.

Attention may be directed to an important point. With simple explosives, such as dynamite, the ignition of fire-damp, if the explosive is liable to effect it, is always and certainly produced.

For certain dual mixtures the phenomena appear to be very constant; but for many others the ignition occurs capriciously, being produced on one day and not on another. This singularity will be explained in a later chapter.

IV.—THEORETICAL INQUIRIES.

Ignition of Gaseous Mixtures.—Two of the members of the Sub-Commission, in previous researches (*), estimated the temperature of ignition of fire-damp at about 1,202 degs. F. These observers, however, laid great stress on the *considerable retardation of ignition*, which may occur in mixtures of fire-damp with air or even with oxygen. This retardation is naturally greatest when the temperature, to which the mixture is heated, is about 1,202 degs. F.; at this temperature even, the retardation may amount to ten seconds.

This allows the perception of the possibility of this fact, in appearance paradoxical, that with a gaseous mixture inflammable at 1,202 degs. F., gases may be produced, without causing the explosion of the mixture, whose temperature is, as shewn hereafter, above 3,632 degs. F. But as these gases have been formed by the *detonation* of an explosive, they are suddenly given off, and under a very high pressure; they expand and cool with extreme rapidity (in some thousandths of a second), before having had time to ignite the mixture of air and fire-damp with which they come in contact.

Would the previous experiments have given an altogether different result had they been made in a mixture of any other gas than fire-damp? A cartridge made up of equal parts of dynamite and Blanzy coal-dust, which does not ignite mixtures of fire-damp, does ignite mixtures of air and coal-gas (†).

These mixtures, however, still shew a certain retardation of ignition; with mixtures of air and hydrogen, this phenomenon, if it exists, is less marked; and it has been found that a plugged cap of 23 grains of fulminate, which ignites neither fire-damp nor coal gas, ignites hydrogen.

(*) Mallard and Le Chatelier.—Researches on the Combustion of Explosive Gaseous Mixtures. Annales des Mines. 8th Series. Vol. IV., p. 274, 1883.

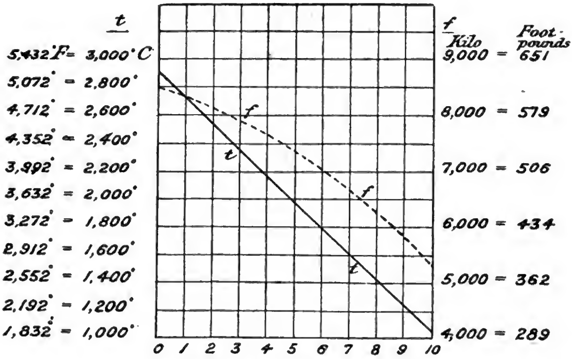
(†) The experiments with coal-gas have been commenced; but are not yet completed.

Temperature of Detonation of Explosives—Formulæ for its Calculation.—It is customary to look upon explosives only as regards their force, that is to say, the intensity of the mechanical effects which they may produce. They are now to be considered from a different point of view. The chief consideration now, is not the force developed, but the temperature produced. This leads to an endeavour to calculate the temperature of detonation of a mixture, whose composition, the laws of its decomposition, and the thermo-chemical phenomena by which it is characterised, are known.

The process of these calculations is well known. As it is important to obtain figures as near as possible to the real temperature of detonation, the increase of the specific heat of gases, as established by the experiments of Messrs. Berthelot and Vieille, and by those of Messrs. Mallard and Le Chatelier, is introduced. The formulæ given by the latter for carbonic acid, aqueous vapour, and the so-called perfect gases (elementary gases, carbon monoxide, hydro-chloric acid, &c.) have also been used (*).

These calculations have been applied to numerous explosive substances, and more particularly to mixtures of dynamite and of nitrate of ammonia, endecanitric cellulose with nitrate of ammonia, and octonitric cellulose with nitrate of ammonia. The results are graphically shewn by the curves (Figures 5, 6, and 7). For each of the three above-named mixtures, two curves are shewn, having for abscissas the weights of nitrate contained in ten parts by weight of the mixture. One of the curves has for ordinates the temperatures of detonation t, the other the quantity f, which somewhat defines the power of the explosive, and which is expressed by the equation—

$$f = \frac{v_0 \, T \times 1{\cdot}033}{\omega \times 273}$$



Parts of nitrate of ammonia in ten parts of mixture.

Figure 5.—Dynamite and nitrate of ammonia.

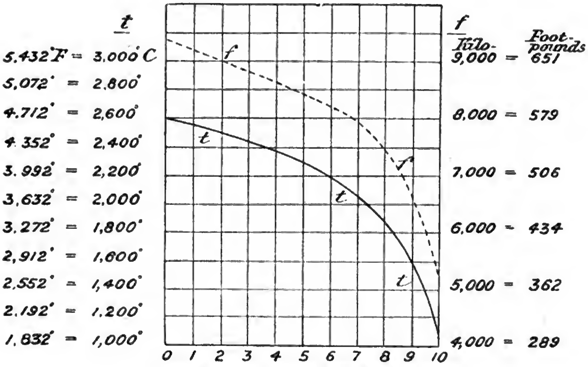
(*) See page 57.

in which

v_0 the volume of the gases produced by the explosion, reduced to 0° Cent. and 760 mm. (29·92 inches) of mercury ;

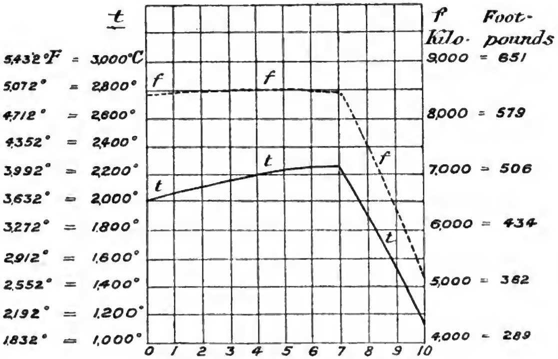
ω, the weight of these gases ;

T, the absolute temperature of explosion.



Parts of nitrate of ammonia in ten parts of mixture.

Figure 6.—Endecanitric cellulose and nitrate of ammonia.



Parts of nitrate of ammonia in ten parts of mixture.

Figure 7.—Octonitric cellulose and nitrate of ammonia.

With mixtures of dynamite and nitrate of ammonia the decomposition occurs with excess of oxygen, and the gases are completely burnt.

With mixtures of nitric cellulose and nitrate of ammonia, the mode of decomposition, described in the note by Messrs. Mallard and Le Chatelier(*) added to the report is adopted. When the amount of oxygen is not sufficient to completely burn the combustible gases to carbonic acid gas and water, it is supposed that the oxygen, after converting the whole of the carbon into carbon monoxide, is divided between this gas and the hydrogen.

Pressure Developed by Explosives.—Formulæ for its Calculation.—The exactness of the results given by calculations have been compared with the pressure readings made by Messrs. Sarrau and Vieille.

The pressure P, developed in a volume V, with a charging density Δ, may be obtained by using the formula of Clausius

$$\left[\frac{P}{p_0}+\frac{c}{T\left(\frac{V}{v_0}+\beta\right)^2}\right]\left(\frac{V}{v_0}-u\right)=\frac{T}{273},$$

when c, β, u are co-efficients peculiar to each gas.

For high temperatures, and as long as the ratio $\frac{V}{v_0}$ is not too small, the expression

$$\frac{c}{T\left(\frac{V}{v_0}+\beta\right)}$$

may practically be eliminated.

The co-efficient u, which may be called the *co-volume*, is nearly the same for all gases, as shewn by the experiments of Mr. Amagat and the calculations of Mr. Sarrau, and may be taken as equal to 0·001. (†)

Therefore $$\frac{P}{p_0}\left(\frac{V}{v_0}-u\right)=\frac{T}{273}$$

It is remarked that with a charging density of Δ, then

$$V=\frac{\omega}{\Delta},$$

this formula becomes $$P=\frac{\frac{p_0\,v_0\,T}{\omega\times 273}\Delta}{1-\frac{u\,v_0}{\omega}\Delta}=\frac{f\Delta}{1-\alpha\Delta},$$

in which the co-efficients f and α can be calculated, so that the theoretical figures may be compared with the experimental values.

Comparison of Theoretical with Experimental Pressures.—This comparison is made more simple, if the last equation is put into the form

$$\frac{P}{\Delta}=\alpha\,P+f.$$

The line which has $\frac{P}{\Delta}$ for ordinates and P for abscissæ should be a straight line whose angular co-efficient is α and the ordinate at the commencement is f.

(*) See page 59. (†) See page 58.

Figure 8 shews the position of these straight lines given by this equation, for

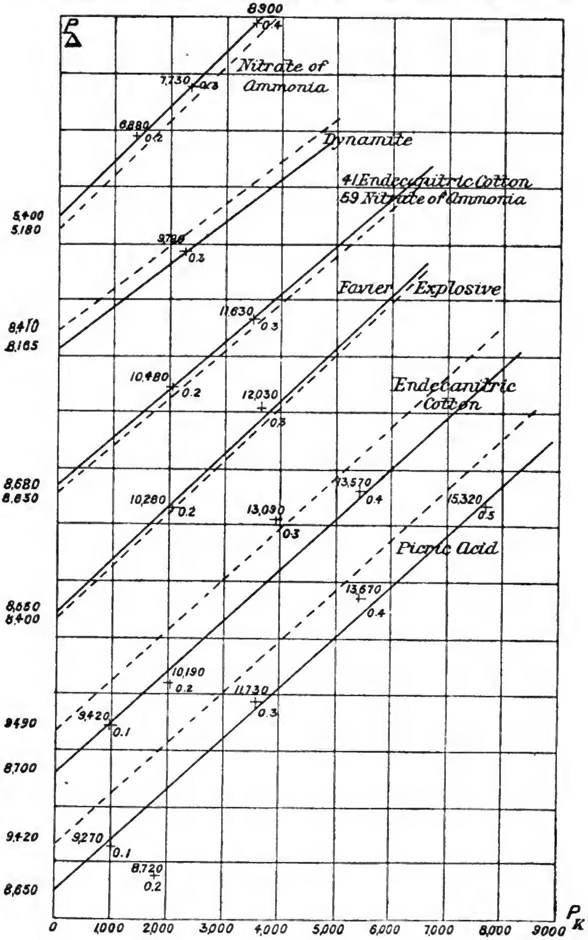


Figure 8.

Lines representing the formula $\frac{P}{\Delta} = a\ P + f, \quad a = \frac{u\ v_0}{\omega}$.

Theoretical lines shewn - - - - - - Experimental lines shewn ——

nitrate of ammonia, dynamite, gun-cotton, a mixture of 60 per cent. of nitrate of ammonia with 40 per cent. of military cotton, the Favier explosive, endecanitric cellulose and picric acid.

Each of these lines has been traced with the calculated angular co-efficient a. The dotted line in the figure is the theoretical line; the continuous line is drawn as near as possible to the experimental points, always with the same angular co-efficient a.

The difference between the theoretical and the experimental lines for nitrate of ammonia, the Favier explosive, and the mixture of cotton and nitrate is less than the possible errors of observation and calculation. For dynamite the difference is only $\frac{1}{30}$. This concordance is closer than might have been expected.

For gun-cotton the difference is as much as $\frac{1}{10}$, taking the latest pressure readings quoted by Messrs. Berthelot and Vieille in their paper on fulminate of mercury, in which the results are not perfectly concordant. But in this case, a substance is being considered whose chemical composition is uncertain, and, moreover, whose method of decomposition on explosion is doubtful. The calculations have been made by accepting the mode of decomposition, not actually observed, but assumed by Messrs. Sarrau and Vieille, as being the limit towards which the observed mode tends.

The observations relative to picric acid are found to lie very nearly on a line having the calculated inclination a. The difference between this line and the theoretical line is similar to that shewn by gun-cotton. Picric acid is also a substance whose manner of decomposition is doubtful.

These examples amply prove that the method of calculation employed represents the facts almost exactly. The temperature and the pressure developed by the detonation of any explosive of known composition can, therefore, be calculated with sufficient exactness, provided that the method of decomposition of this explosive, when detonated, is known.

The calculated curves in figures 5, 6, and 7, therefore, represent the phenomena somewhat correctly if the decomposition of the explosive occurs conformably with that assumed in the calculation.

V. EXPERIMENTAL STUDY OF THE UNCONFINED DETONATION OF EXPLOSIVES.

Incomplete Detonation of unconfined Explosives.—Experiment has shewn that a mixture containing 67 per cent. of dynamite, and 33 per cent. of sal-ammoniac ignites fire-damp; that a mixture of 40 per cent. of sal-ammoniac ignites it seldom; and that a mixture of 50 per cent. of sal-ammoniac does not ignite it. Now if the curve which represents the temperatures of detonation of these mixtures be continued downwards, the mixture of 33 per cent. of sal-ammoniac will develope a temperature of 2,732 degs. F.; the 40 per cent. mixture, a temperature of 2,012 degs. F., and the 50 per cent. mixture a temperature of 743 degs. F., if the decomposition can be considered as complete in each case. Moreover, this assumption is certainly incorrect for the 50 per cent. mixture, because, at the temperature of 743 degs. F., sal-ammoniac is not decomposed. Admitting the correctness of the hypothesis for the other mixtures, it may be concluded that the temperature, which the gases from the explosion should not surpass to ignite the fire-damp, is lower than 2,912 degs. F. This deduction is not correct, as will be shewn hereafter.

Lastly, it may be said that explosives, especially if they consist of dual mixtures, on the contrary, are not always decomposed in a complete manner when exploded unconfined.

Method of Experiment.—It is interesting to study this fact with precision. For this purpose the amount of heat developed by the detonation of an unconfined explosive, was measured by, in some way, transforming the boiler into a calorimeter. A cartridge, exactly weighed, is fired in the boiler, closed and filled with air. A water-gauge is used to measure at known intervals, starting from the moment of firing, the excess pressure P′—P of the air in the boiler above the initial pressure. A curve, representing these observations, is used to determine, by extension, the pressure exerted at the moment of detonation, which cannot be directly observed on account of the shock imparted at that moment to the water in the water-guage. Figure 9 shews examples of the curves so drawn. The precise significance of the figured curves will be indicated further on.

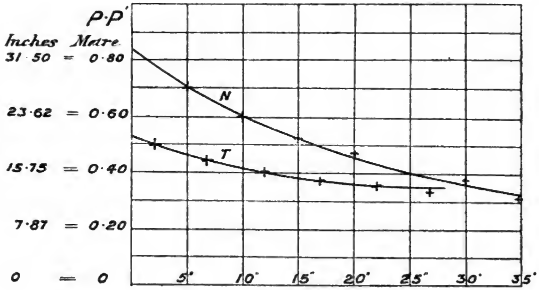


Figure 9.

N, Curve of the pressures for a cartridge containing 772 grains of dynamite, unconfined.

T, Curve for a cartridge of 772 grains of dynamite contained in the tube of 0·98 inch, and 1·57 inches.

The measurements thus made are evidently inexact; however, they are sufficient for the desired object.

The volume of the boiler being 359·2 cubic feet, the volume of gases resulting from the explosion of the cartridge (the weight of which is from 772 to 1,543 grains) is relatively insignificant.

The increase of the pressure of the air inside the boiler is, therefore, almost entirely due to the increase of temperature of this air, raised from t to t' by the effect of the heat Q developed by the detonation. If ω be the weight of air in the boiler, and c the specific heat with constant volume, then

$$\omega\, c\, (t'-t) = Q.$$

Moreover, P and P′ being the pressures expressed in metres of water before and after the detonation, $T = t + 273$ the absolute temperature of the air before explosion, P its pressure in metres of water, then—

$$\frac{P' - P}{P} = \frac{t' - t}{T};$$

whence,

$$P' - P = \frac{P}{T} \times \frac{Q}{\omega\, c}.$$

Again,

$$P = 10{\cdot}33 \times \frac{H}{760}$$

$$\omega = 10{\cdot}171 \times 1{\cdot}293 \times \frac{273}{T} \times \frac{H}{760};$$

whence, taking $c = 0{\cdot}168$

$$P' - P = 0{\cdot}0171\ Q,$$

and

$$Q = 58{\cdot}4\ (P' - P),$$

[in which H is the height of barometer in millimetres of mercury, 10·171 cubic metres is the capacity of boiler, and 1·293 kilogrammes is the weight of one cubic metre of air at normal temperature and pressure.]

Experimental Result for Dynamite.—Almost completely detonated unconfined.—Take the case of dynamite. A cartridge (curve N fig. 9) of 772 grains of dynamite (Vonges at 75 per cent.), detonating unconfined, develops a pressure

$$P' - P = 0{\cdot}83.$$

Hence

$$Q = 48{\cdot}5,$$

and for 100 grammes (1,543 grains),

$$Q = 97.$$

The heat produced by the complete decomposition of dynamite, may be reckoned at 1,110 calories, or 55·5 calories for 50 grammes. The silica, however, absorbs a certain quantity of heat which is taken at 138 calories (the temperature of detonation of dynamite being equal to 5,252 degs. F., and the specific heat of the earth being 0·19). If this quantity of heat is not immediately restored to the air in the boiler, the quantity of heat Q would not be more (for 10 grammes) than 97·2 calories. The figure differs so little from that observed experimentally, that it may be assumed that the detonation of unconfined dynamite causes its complete decomposition.

Experimental Results for Various Explosives.—If similar calculations are made for the other explosives, the results contained in the annexed table are obtained.

This table shews that dynamite, as previously mentioned, detonates almost perfectly when unconfined.

Military gun-cotton (= ·81 cubic inch) approaches very nearly to complete detonation under the same conditions.

In mining gun-cotton, even for certain mixtures, low in nitrogen, of cotton of ·68 and of nitrate of ammonia, and for mixtures of dynamite and of sal-ammoniac, the amount of heat disengaged on detonation is greater than the theoretical quantity.

With most of the other explosives the amount of heat disengaged on detonation is less than the theoretical amount; it should be concluded from this that these explosives only detonate imperfectly when unconfined.

This imperfect detonation is doubtless due to the fact, that the reactions assumed in theory, and which are actually produced in a closed vessel, as will be shewn further on, have not time to be produced, when the explosive is not confined, in the infinitely short time during which the gases are kept in contact. Not only are the reactions very incomplete, but they become altogether different reactions from those expected. Mr. Berthelot has laid great stress on this possible variation in the nature of the decompositions and reactions, more especially in the case of nitrate of ammonia.

Moreover, one imagines that the phenomena would be still more marked with dual explosives, in which it is assumed: (1) That the detonation of one of the two substances entails that of the other, and (2) that the gases produced by the simultaneous detonation react on each other. These two hypotheses may both fail together, or the first may be realised without the second.

Nature of Explosives.	Weight of Cartridge	Weight of Fulminate in Detonator	Pressure (P′—P) Observed in Inches of Water.	Q deduced for 1,543 grs.	Q theoretical for 1,543 grs.
	Grains.	Grains.	Inches.	Units of Heat.	Units of Heat.
Dynamite (75 °/₀)	771·6	23·15	32·68	385·1	385·9
Military Cotton (=·81 cubic inch)	771·6	23·15	28·35	349·4	412·9
Mining Cotton (=·76 cubic inch)	771·6	23·15	58·27	682·8	408·9
Blasting Gelatine (Paulilles)...	617·3	23·15	22·05	318·4	609·3
Do.	771·6	23·15	27·17	319·9	
Bellite	771·6	23·15	9·84	115·9	397·8 (1)
Do.	771·6	23·15	11·02	129·8	
Do.	771·6	46·30	13·39	158·0	
Pyroxyline-Powder (Moulin-Blanc) ...	771·6	23·15	17·52	202·5	325·5 (2)
Do.	771·6	23·15	20·47	241·4	
Do.	771·6	23·15	23·62	277·9	
Do.	1003·1	23·15	24·02	217·2	
Cotton 58, Nitrate of Barium 42	771·6	23·15	27·56	325·5	321·6 (3)
Cotton (=·68) 20, Ammonia Nitrate 80 ...	771·6	23·15	5·91	69·5	317·6
Do. 25 do. 75 ...	771·6	46·30	16·14	190·6	361·3
Do. 35 do. 65 ...	771·6	23·15	16·93	198·5	404·9
Do. 60 do. 40 ...	463·0	23·15	13·78	270·4	381·1
Do. 80 do. 20 ...	463·0	23·15	24·80	488·3	325·5
Do. 90 do. 10 ...	463·0	23·15	37·01	726·5	301·7
Dynamite 20, Ammonia Nitrate 80 ...	771·6	23·15	8·86	104·8	198·5
Do. 67, Ammonia Alum 33	771·6	23·15	17·52	206·4	210·4 (4)
Do. 50, Sal-Ammoniac 50	771·6	23·15	16·54	195·3	39·7 (5)
Do. 60 do 40	771·6	23·15	17·32	204·4	138·9
Do. 67 do. 33	771·6	23·15	20·87	246·1	194·5

(1) Calculated assuming 17·5 per cent. dinitro-benzol, and 82·5 per cent. of nitrate of ammonia.

(2) Decomposed to Ba CO_3.

(3) Decomposed to Ba CO_3.

(4) Quantity of heat calculated assuming complete combustion of the nitro-glycerine, and simple dehydration of the alum.

(5) These quantities of heat are calculated on the supposition of the decomposition of the sal-ammoniac into $HCl_2 + N + 3H$, and the complete combustion of the nitro-glycerine.

The first case is that of mixtures of dynamite and of sal-ammoniac, which develop an amount of heat little inferior to that caused by the detonation of dynamite alone. The speed of decomposition of the sal-ammoniac is too slow to allow time for that decomposition to be effected, and the effect of the detonation of the dynamite is doubtless to decompose a very small part of the mixed salt and to project the rest which acts as an inert body.

It will be seen later on that the decomposition of sal-ammoniac has not sufficient time allowed, even when the explosive is stemmed in a tin tube of ·98 and 1·57 inches in diameter.

Ammonia-alum, mixed with dynamite, seems to act differently to the sal-ammoniac, as the quantity of heat observed is almost equal to that deduced from the combustion of the nitro-glycerine and the dehydration of the alum. It will be shewn, however, later on that there is reason to doubt the correctness of this conclusion.

Moreover, these facts very well explain the capricious phenomena that explosives, especially the dual explosives, produce, detonating unconfined, as regards the ignition of fire-damp. When an explosive is not completely detonated, the reactions consequent on its detonation cannot be precisely defined, and may vary a great deal, under the influence of secondary conditions. Notably, they will vary when the explosive is fired by a more or less powerful detonator; when the explosive, at the moment of detonation, is raised to a more or less high temperature, the elevation of temperature producing complete detonation, &c.

The anomalies met with in the Prussian experiments, and in the French, thus receive a satisfactory explanation.

It is supposed consequently, that the safety of an explosive, detonating imperfectly when unconfined, cannot be completely assured, if, among all the possible methods of decomposition for this explosive, even one is found liable to ignite fire-damp.

The object to be attained in the search for an explosive of perfect safety, if one exists, is, therefore, to find an explosive, always detonating completely when unconfined without igniting fire-damp; or to find an explosive which, when partially detonating, cannot take any mode of decomposition capable of igniting fire-damp.

Peculiar Phenomena Exhibited by Low-nitrated Cottons, Detonating Unconfined.—A very curious fact, an apparent paradox, is that compressed mining cotton always ignites fire-damp, and that compressed military cotton, though more highly nitrated, and having a higher temperature of detonation, does not always ignite it. The experiments on detonation explain this anomaly.

Indeed, the detonation of a cartridge of 772 grains of military cotton has twice given a pressure equal to 28·35 inches, which corresponds very nearly, as already mentioned, to the complete decomposition of the cotton.

A 772 grain cartridge of mining cotton has twice consecutively produced a proportionately enormous pressure, which the pressure gauge could only imperfectly register, but which must have been higher than 58·27 inches, corresponding to 341·4 units of heat, or 3,097 units per pound. The decomposition of mining cotton (nononitric cotton) should disengage about (*) 1,862 units of heat per pound (aqueous vapour), and the heat from complete combustion is, according to Mr. Berthelot, about 4,232 units.

It is, therefore, perfectly evident that the gases yielded from the explosion of mining cotton are, after the explosion, burnt almost completely when unconfined.

Why does this phenomenon not occur with military cotton, whose gases are also combustible? It is difficult to reply. All that can be said is that an equivalent of a nitro-cellulose of n degree necessarily yields (if it be assumed that the decomposition produces only CO_2, CO, H_2O, H, and N.), a volume of combustible gas ($CO + 2H$) equal to

$$\left(48-\frac{5n}{2}\right) \times 22{\cdot}32. \qquad (*)$$

(*) See Note A, page 60.

The volume of combustible gas increases, therefore, as n diminishes; it is equal to $25{\cdot}5 \times 22{\cdot}32$ litres $= 568{\cdot}7$ for enneanitric cellulose, and to $20{\cdot}5 \times 22{\cdot}32$ litres $= 457{\cdot}2$ for endecanitric cellulose. The gases from the detonation of the former are, therefore, a little more combustible than those from detonation of the latter. Nevertheless it is singular that such a slight difference should have such a marked effect.

However this may be, this well-ascertained phenomenon immediately explains why cottons low in nitrogen, such as that yielding ·68 cubic inch of NO_2 per grain, and whose temperature of detonation should be less than 3,632 degs. F., easily ignite fire-damp, when military cotton (yielding ·81 cubic inch of NO_2 per grain), whose temperature of detonation is about 4,784 degs. F. does not always ignite it.

The mixtures of cotton-powder (= ·68) and nitrate of ammonia, containing 90 per cent. and 80 per cent. of cotton, when exploded unconfined, disengage an amount of heat greater than the theoretical quantity. The oxygen from the nitrate does not burn off enough of the gases yielded by the decomposition of the cotton for them to remain capable of being completely burnt.

Explanation of the Phenomena presented by Mixtures of Gun-Cotton and Nitrate of Barium—Pyroxyline-Powder.—The same phenomena allows the suggestion of an explanation of a fact which has astonished many. Pyroxyline-powder, which contains 60 per cent. of cotton (= ·71), 30 per cent. nitrate of barium, and 6 per cent. nitrate of potash, ignites the fire-damp only exceptionally, although cotton alone on the one side and mixtures with larger proportions of nitrate of barium on the other side invariably ignite it.

Gun-cotton containing ·71, corresponds almost to octonitric cotton; its temperature of detonation is, therefore, about 3,632 degs. F. It will not ignite the fire-damp if the gases from detonation do not happen to burn unconfined; for it will be demonstrated later that the apparent temperature of ignition of fire-damp, under the influence of explosives, is about 3,992 degs. F.

If the cotton is mixed with a sufficient quantity of nitrate of barium to burn the gases yielded by the explosion, the temperature of the detonation is raised to 4,622 degs. F., if the dissociation of the carbonate after explosion is assumed. This temperature is sufficient to ignite fire-damp.

But if the proportion of nitrate is diminished, the temperature is lowered and the gases of the detonation are burnt sufficiently by the oxygen of the nitrate to be no longer inflammable, and to act like those of military cotton.

Mixtures could, therefore, be found like that constituting the pyroxyline powder, whose temperature of detonation will be so low that they will not ignite fire-damp, at least regularly.

Force of Explosives.—Hitherto the force of explosives has not been considered. This element is not the important element in the matters that have been considered. What the worker of a fiery mine first seeks, is an explosive whose temperature of ignition will be so low that the detonation can never kindle the gas. As for the force of the explosive, generally it is more than sufficient; the worker will be satisfied if the new and safe explosive, which will be given him, does not cost more, per unit of force, than the explosives now in use.

But it is easy to shew that not only does the unit of force cost no more, but that the price may be materially diminished.

Take, for example, mixtures of dynamite and nitrate of ammonia. It is evident on examining the results of figure 5, for the mixture of 80 per cent. of nitrate, the quantity f which measures the pressure obtained is 477 foot-pounds, the same quantity *f* for dynamite alone being 680 foot-pounds. The useful effect of the mixture is, therefore, about three-fourths that of dynamite. But if the selling price of nitrate of ammonia is 4⅔d. per lb., and that of dynamite is 1s. 1d. per lb., the selling price of the mixture will be 6·4d. per lb., that is to say, less than half that of dynamite.

It is true that the fixed duty of 8·6d. per lb. slightly modifies the result and raises the price to 1s. 9½d. per lb. for dynamite, and to 1s. 3d. per lb. for the mixture. But the ratio between these two costs is little less than three-fourths; and doubtless the proportion of nitrate might be increased.

The unit of useful effect can, therefore, be obtained at less cost with this dual explosive than with dynamite. It is true that effects of as great intensity cannot be produced, but these effects are useless and can even become injurious in the working of coal in mines.

Possible Influence of the Aqueous Vapour contained in Air, on the Inflammability of Fire-damp.—In conclusion, an observation which became evident, as soon as the atmospheric temperature became high, and which possibly may have a certain importance, should be mentioned.

On two occasions, the 19th of May and the 4th of June, experiments were made in warm and sultry weather; on the 19th of May especially, the experiments were made in the morning, the weather was oppressive and seemed to presage the thunderstorm which burst in the evening. Explosives which had never ignited fire-damp either before or since, did ignite it on this day. Thus pyroxyline powder, which produced ignition twice consecutively, has never reproduced the same effect since.

On the 4th of June, the stormy character of the weather was less pronounced than on the 19th of May, but still it was very marked, and the mixture of 67 per cent. of dynamite and 33 per cent. of ammonia-alum, which had not ignited gas, either on the 24th of April or the 1st of June, ignited fire-damp on that day. Pyroxyline powder, however, remained unaffected.

It is not believed that the rise in temperature was the only cause of the increase in the inflammability of the fire-damp, for, on the 1st of June, the temperature was higher than on the 19th of May or the 4th of June; but the weather was very dry, and the result in question was not observed. One is inclined to believe that the aqueous vapour, which is present in the air in considerable quantities in warm and stormy weather, would be the preponderant factor. It is possible that the retardation in the ignition of the fire-damp may diminish with the increase in the quantity of the aqueous vapour contained in the air. Indeed it is recognised, and an English chemist, Mr. Dixon in particular, has thrown a light on this phenomenon, that carbon monoxide does not combine with oxygen under the influence of the electric spark when these gases are perfectly dry.

A similar fact for fire-damp mixtures would be of great importance in mines, where the air is most frequently saturated with moisture. Laboratory experiments, which are in progress, but are not yet completed, can alone make this question clear.

Summary.—In reviewing this first part of the researches, it may be said, without entering anew into details of the experiments, that they demonstrate that it is possible, by mixing certain substances with explosives whose detonation ignites fire-damp, to lower the temperature of this detonation, so that the resulting gases do not ignite, at least under ordinary conditions, the fire-damp mixtures amongst which they are detonated unconfined.

Among the mixtures tested by the Commission, those which are the most worthy of examination, are—

(1) The pyroxyline powder of Moulin-Blanc, which, however, under circumstances perhaps rather exceptional, has twice ignited fire-damp, the total number of trials being 19.

(2) The mixture of 20 per cent. of gun-cotton (low in nitrogen) with 80 per cent. of nitrate of ammonia, whose theoretical temperature of ignition is 3,488 degs. F. with $f = 542$ foot-pounds, which in seven trials did not once cause ignition.

(3) The mixture of 20 per cent. of dynamite with 80 per cent. of nitrate of ammonia, whose theoretical temperature of ignition is 2,732 degs. F. with $f = 453$ foot-pounds, which has not produced ignition of gas, although only two trials were made.

(4) Bellite, whose composition is not known with certainty, whose detonation, difficult when unconfined, is incomplete, even with 46 grains of fulminate, and which under these conditions has only been thrice tested, and did not ignite the fire-damp.

With the composition as given by the inventor, the temperature of detonation would theoretically be 3,967 degs. F. with $f = 217$ foot-pounds.

(5) Lastly, the Favier explosive, whose theoretical temperature of detonation would be 3,848 degs. F., and which apparently does not explode at all when unconfined, even with heavy charges of fulminate; whose practicability of detonation under working conditions is not well known; whose intermediate detonator, such as has been proposed by the inventor, should be suppressed, and which reduced, it is true, to a state of fine powder, has once ignited a gaseous mixture.

The trials made with bellite and the Favier explosive cannot be considered as finished. It has been thought proper to mention these two explosives here, because the experiments already made do not appear unfavourable, and they seem to theoretically be among the class of substances incapable of igniting fire-damp mixtures.

The substance which appears the most suitable for diminishing the temperature of detonation of explosives such as dynamite and gun-cotton is nitrate of ammonia. The other substances which may be mixed with the explosive, such as hydrated carbonate of soda, hydrated sulphate of soda, ammonia-alum, and sal-ammoniac, are only very partially decomposed by the detonation, and their action is, for that reason, more uncertain.

The trials made with mixtures of dynamite or of cotton with nitrate of ammonia should be continued, and it is permissible to hope that there may be formed with these substances, mixtures in varied proportions possessing, along with great certainty of safety, all the degrees of explosive power which may be regarded as necessary in practice.

CHAPTER III.

EXPLOSIVES FIRED IN A CLOSED VESSEL.

MUCH time has been devoted to the phenomena which explosives exhibit when detonated unconfined, although this method of detonation, for which they are not intended, ought to be prohibited in mines. But it is evidently under these conditions that explosives present the maximum danger, and under which it is easier to classify them as regards safety.

Moreover, it may often accidentally happen, in consequence of the imprudence or inattention of a workman, or from any other cause, that the explosive used in the workings may be detonated before being stemmed in the bottom of the shot-hole. The danger peculiar to unconfined detonation is not, therefore, purely imaginary.

It is none the less true that in normal use, explosives should be fired in a closed vessel, and the dangers which can arise under these conditions, will now be examined.

Process of Experiment.—When an explosive detonates at the bottom of a shot-hole, if the shot is not blown out, fissures more or less great are produced in the broken mass, through which the resulting gases escape. The variety of means by which this effect can occur is infinite, but in almost all, if not in all, cases the gases of the explosion only come in contact with the external air, after having exerted a certain mechanical work on the rock.

To realise something analogous in the boiler, but under conditions certainly more dangerous than those which can be met with in practice, the explosive enclosed in a metallic tube of lead or of tin closed at the bottom, and open at the top, was suspended in the midst of the fire-damp. The explosive, in this tube, rested on a plug of 2 to 2½ inches of clay or sand ; it was covered with a stemming of clay, of sand, or even in certain cases, of coal-dust, generally 4 inches to 4¾ inches thick.

The detonation, when it occurred, projected in a state of metallic dust the part of the tube with which it was in contact. The lower and the upper parts of the tube usually remained nearly intact at the bottom of the boiler.

The nature of the metal (lead or tin), and especially its thickness, could be varied. These observations, however, have not been made, and would be of interest only with unconfined explosives igniting fire-damp.

Experimental Results.—Under normal conditions of detonation, the explosive being well rammed against the sides of the tube and between the two tampings, the facts summarised in the annexed table were observed.

Doubtless, all explosives cease to ignite gas when the thickness of the sides of the tube is sufficiently great, but the thickness adequate to produce this effect varies with the explosive.

With gun-cotton, a lead tube of 1·18 inches and 1·38 inches, and only ·10 inch thick, is sufficient to hinder ignition.

With dynamite No. 1, a lead tube 1·06 inches and 1·57 inches, or a tin tube of 0·98 inches and 1·57 inches is required.

Gelatine-dynamite acts nearly the same as No. 1 dynamite.

Nature of Explosive.	Internal and External Diams. of Tube.	Nature of Tube.	Action on the Gaseous Mixtures.
	In. In.		*
Dynamite No. 1	1·06 — 1·57	Lead	N
Do.	1·18 — 1·57	do.	I
Do.	1·18 — 1·38	do.	I
Do.	0·98 — 1·57	Tin	N
Mining Gun-cotton	1·26 — 1·65	Lead	N
do. do.	1·18 — 1·38	do.	N
Blasting-Gelatine	0·98 — 1·57	Tin	I
Gelatine-Dynamite	1·06 — 1·57	Lead	N
Ammonia-Dynamite	0·98 — 1·57	Tin	N

* N signifies non-ignition of fire-damp. I signifies ignition of fire-damp.

With blasting-gelatine, the tin tube of 0·98 inches and 1·57 inches is not sufficient to prevent the ignition of the fire-damp; this is in accordance with the considerable amount of heat developed by this explosive, which, amongst all those derived from dynamite, should be considered as the most dangerous.

Explanation of the Effect Produced, as regards the Ignition of Fire-damp by the Tube which Envelops the Explosive.—Work Developed by the Bursting of the Sides of the Tube.—It may be asked, what is the cause of the effect produced by the tube, which, on the whole, does not prevent the gases of the explosion from coming very rapidly, and at a very high temperature, in contact with the fire-damp mixture. It appears that this cause should be solely attributed to the cooling which the gases undergo in consequence of the mechanical work which has to be expended to impart a certain kinetic energy to the sides of the shattered tube.

This mechanical work is considerable, and may be estimated in a very simple manner by exploding the cartridge, stemmed in its tube, in the midst of the closed boiler filled with air, and registering the pressure caused by the explosion, as has been previously remarked. The observed initial pressure P′—P gives, when multiplied by the co-efficient 58·4 (see page 28), the amount of heat Q′ imparted to the air in the boiler after the explosion. But this amount of heat is equal to that Q, set free on explosion, diminished by the amount of heat AU, equivalent to the kinetic energy U, communicated to the walls of the tube.

If, first of all, by the unconfined detonation of the same explosive, Q has been measured; AU can be found by subtraction.

Under these conditions, a cartridge of 50 grammes (772 grains) of No. 1 dynamite has given (*) :—

When unconfined a pressure P′—P = ·83 metre of water, corresponding to Q = 48·5.

(*) See the curves of pressure deduced from observation (p. 27, Fig. 9). It will be remarked that the progress of cooling indicated by the curve corresponding to detonation in the tube is slower than that corresponding to unconfined detonation. The heat transformed into kinetic energy communicated to the fragments of the tube, is brought back into the state of heat by the impact of the fragments against the shell of the boiler, and this heat is gradually restored to the air in the boiler, which retards the progress of the cooling.

In a tin tube of 0·98 inch and 1·57 inches, $P'-P$ = ·525 metre of water, $Q' = Q - AU = 30{\cdot}6$.

Therefore,

$$AU = 17{\cdot}9, \text{ and } \frac{AU}{Q} = \frac{17{\cdot}9}{48{\cdot}5} = 0{\cdot}37.$$

The amount of heat transformed into work by the disruption of the sides of the tube and by the projection of the fragments, varies, moreover, with the nature and size of the tube. Other things being equal, it diminishes with the thickness.

Working always with dynamite it was found that, with a lead tube of 1·26 inches and 1·65 inches, the portion of heat absorbed in mechanical work is about ·44.

With a lead tube of 1·18 inches and 1·38 inches this portion is ·33.

In this experiment, therefore, a little more than a third part of the total heat is transformed into work. This is about half of the transformation that the expansion of the hot gases resulting from the explosion of dynamite, thoroughly stemmed in a close space, would theoretically be able to produce.*

Apparent Temperature of Ignition of Mixtures of Fire-damp and of Air under the Influence of Explosives.—The experimental results obtained with dynamite, moreover, allow the calculation (at least approximately) of the temperature which the gases produced by the detonation of the explosive should possess, in order to ignite the mixture of fire-damp and air.

In fact, since the expansion of the gases produced by the detonation of the dynamite has lost, by communicating it as kinetic energy to the sides of the tube, ·37 of its quantity of initial heat, it preserves no more than ·63 of it.

By a calculation similar to that used to ascertain the temperature of detonation, it is found that the gases, at the moment when the tin tube, of 0·98 inches and 1·57 inches, has been shattered, come in contact with the inflammable mixture, they have a temperature of 3,902 degs. F. The mixture not igniting by this contact, it can be said that the *apparent* temperature of ignition is, under the conditions of the experiment, above this figure.

After the projection of the tube of 1·18 inches and 1·38 inches, the temperature of the gases should be 4,136 degs. F.; but they ignite the fire-damp. The *apparent* temperature of ignition of the mixture of fire-damp and air will, therefore, be, as far as can be judged from purely approximate calculations, between 3,902 degs. F. and 4,136 degs. F., or about 3,992 degs. F.

If the same calculation is made for blasting-gelatine fired in a tin tube of 0·98 inches and 1·57 inches, it is found that the temperature of the gases, after the bursting of the sides of the tube, should be about 4,352 degs. F. These gases consequently ignite the fire-damp mixture.

It must be recollected that the high value of the *apparent* temperature of ignition of fire-damp, deduced from observations, is due, at least in great part, to the considerable delay of the ignition displayed by fire-damp mixtures, and to the very rapid expansion of the gases resulting from the detonation of explosives, which causes an extremely quick cooling. It consequently applies only to the particular experimental conditions under which it was obtained.

Explosion amongst Water.—Trials were made as to what effect can be attributed to the Settle cartridges, formed, as previously mentioned, of an impermeable paper tube, closed at the bottom, which can be filled with water, and in the midst of which the explosive is placed. This tube is intended to be placed in the shot-hole, which it fills. It has a greater diameter than that of the explosive cartridge which is isolated from the sides by metal projections.

(*) See note B, page 71.

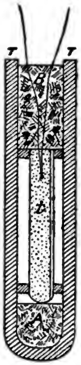


Figure 10.

It was found on suspending the Settle cartridge in the midst of a fire-damp mixture, and placing a cartridge of powder in the midst of the water, that the detonation of the latter caused the ignition of the external gas.

When the powder was replaced by a cartridge of 772 grains of dynamite, the same effect was produced once in two trials.

Variation of Work Developed by the Gases of the Explosion with Density of Charging.—Tests were made as to what effect an empty space left between the explosive and the tube could produce; or, to put it more generally, the variation of what may be called the density of charging; that is to say, the proportion between the weight of the explosive and the volume which it occupies in the tube.

With this object 401 grains of dynamite were rammed into a tube of thin glass, of an external diameter less than 1 inch, and this little tube was placed inside a tin tube of 0·98 inch and 1·57 inches, closed at one end, and above a plug of clay of 2 inches thick. The upper part of the tin tube was stemmed from 4 inches to 4¾ inches thick with clay.

This method of charging is shewn in fig. 10, where *t* is the internal glass tube filled with dynamite, TT the tin tube, A the clay plug, and B the clay stemming.

Under these conditions, the two curves of the variation of pressure are shewn by fig. 11.

The initial pressure developed by the 26 grammes (401 grains) of dynamite detonating unconfined (curve T), may be deduced :—

$P'—P = {\cdot}420$ metre of water, whence $Q' = 24{\cdot}5$.

This result is in accordance with the experiment made with 50 grammes (772 grains).

As to the detonation in the internal glass tube inside the tin tube, the initial pressure is found to be—

$P'—P = {\cdot}330$ metre of water, whence $Q'' = 19{\cdot}3$.

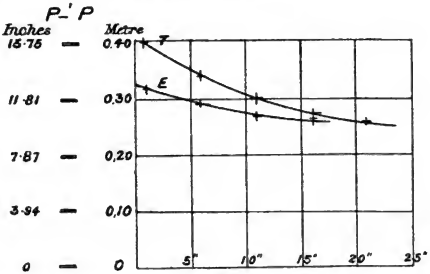


Figure 11.

T, Curve of pressures for a cartridge of 401 grains of dynamite detonating unconfined.

E, Curve of pressures for a cartridge of 401 grains of dynamite filling a thin glass tube, stemmed inside a tin tube of 0·98 inch by 1·57 inches.

Under these new conditions of charging, the quantity of heat AU expended in mechanical work is equal to 5·2 calories, and the proportion of this quantity to the total amount of heat given off from the explosion is only $\frac{5 \cdot 2}{24 \cdot 5} = \cdot 21$.

The mechanical efficiency which with ordinary stemming was about $\frac{1}{3}$, is now no more than about $\frac{1}{5}$. (*)

This difference can be accounted for, by noting that the density of charging being diminished, the gases of the explosion expand themselves in the tin tube before exerting pressure on its sides, and maintaining their temperature, because there has been no work effected. The pressure exercised by the gases on the walls of the tube being less, these sides are projected with less force and acquire less kinetic energy, whence there results a less production of mechanical work.†

It follows naturally for that reason that the temperature of the gases, after the destruction of the tube, is less reduced, and in consequence higher than under the normal conditions of stemming.

Under the preceding conditions, with the internal glass tube inside the tin tube of 0·98 inches and 1·57 inches, it was found that the temperature of the gases of the explosion, after the mechanical work effected, was equal to 4,568 degs. F. The gases of the explosion, which do not ignite fire-damp under normal conditions of stemming, can, therefore, ignite it under these new conditions. This has been verified with a lead tube of 1·06 inches and 1·57 inches. A cartridge of 463 grains of dynamite, which, stemmed in the metallic tube in the ordinary way, does not ignite fire-damp, ignites it every time when it is placed in an internal glass tube stemmed into the lead tube, as has been observed.

For a similar reason, dynamite simply poured into a lead tube of 1·26 inches and 1·65 inches, and then stemmed, ignites fire-damp, although under the same conditions dynamite rammed down does not ignite it.

From this, the very important practical conclusion is deduced, that it is always necessary to ram down and carefully stem, though not excessively, the explosives in the shot-hole ; they work better and are less dangerous.

By varying the shape of the vessel, which contains the explosive, the density of charging is not affected, but the work imposed per unit of volume of the gases produced by the detonation is varied. For example, by flattening the tube, the work is increased. Thus the observed fact that dynamite enclosed in a lead tube, of circular section of 1·18 inches and 1·57 inches, ignites the gas, although ignition is not produced when the same tube is flattened.

It has been shewn that the gases of the detonation issuing from the tin tube of 0·98 inch and 1·57 inches, which contains the internal glass tube filled with dynamite, should possess a temperature of about 4,532 degs. F. They no longer ignite the gas, but this effect must be on the point of production, for with a lead tube of 1·06 inches and 1·57 inches ignition took place. It appears consequently that the apparent temperature of ignition is a little above 4,532 degs. F. By another method, it was found to vary between 3,902 degs. F. and 4,136 degs. F. The discordance between these two estimates will not appear considerable, if the numerous sources of error which might affect them are considered. The latter value is a special function of very numerous variables, such as the dimensions of the internal glass tube, the space left between the sides of this tube and those of the metallic tube, and possibly even the shape of this space. For these

---

(*) This experiment shews there is no advantage in placing the explosive in a more or less enlarged cavity, as has been often suggested for the purpose of increasing the useful effect of this explosive.

(†) See Note B, page 71.

various reasons, the first estimate, which fixes the apparent temperature of ignition of fire-damp mixtures at about 3,992 degs. F., appears to deserve most confidence.

Method of Detonation of Various Explosives in a Closed Vessel.—Experimental Researches.—The results given by the detonation of explosives in tubes, have been made use of, in order to gain some notion of the method of decomposition of these explosives in a closed vessel.

Indeed, if an explosive properly stemmed in a tin tube of 0·98 inch and 1·57 inches, is detonated in the boiler, and if the compression produced is measured, this compression will correspond to about ·63 of the heat developed by the explosion, which can thus be at least approximately measured.

The results contained in the following table have been so obtained :—

NATURE OF EXPLOSIVE.	Weights of		Tubes.		P′—P	(a)	(b)
	Cartridges.	Detonators.	Metal.	Diameters.	Pressure in inches of water.	Q	Q
	Grains.	Grains.		In. In.	In.		
Dynamite, of 75 per cent.	771·6	23·15	Tin	0·98 — 1·57	20·67	...	385·9
	771·6	23·15	Lead	1·26 — 1·65	18·11	...	
	771·6	23·15	Lead	1·18 — 1·38	22·24	...	
Blasting-Gelatine (Paulilles) ...	771·6	23·15	Tin	0·98 — 1·57	24·41	456·5	609·3
Bellite	771·6	23·15	Lead	1·18 — 1·38	18·50	393·0	397·8
	771·6	23·15	Tin	0·98 — 1·57	20·08	377·1	
Pyroxyline-Powder (Moulin-Blanc)	771·6	23·15	Tin	0·98 — 1·57	18·50	345·4	325·5 to 397·0
20 per cent. Dynamite—80 per cent. Ammonia Nitrate	771·6	23·15	Tin	0·98 — 1·57	11·02	205·6	198·5
67 per cent. Dynamite—33 per cent. Ammonia-Alum	771·6	23·15	Tin	0·98 — 1·57	14·96	281·9	131·0
60 per cent. Dynamite—40 per cent. Sal-Ammoniac ...	771·6	23·15	Tin	0·98 — 1·57	14·57	271·9	138·9
67 per cent. Dynamite—33 per cent. Sal-Ammoniac ...	771·6	23·15	Tin	0·98 — 1·57	16·54	309·7	194·5
60 per cent. Cotton (=·68)—40 per cent. Ammonia Nitrate	463·0	23·15	Tin	0·98 — 1·57	11·81	369·2	381·1
80 per cent. Cotton (=·68)—20 per cent. Ammonia Nitrate	463·0	23·15	Tin	0·98 — 1·57	11·02	345·4	325·5
90 per cent. Cotton (=·68)—10 per cent. Ammonia Nitrate	463·0	23·15	Tin	0·98 — 1·57	9·05	281·9	301·7

(a) Q, deduced reckoning the fraction lost in mechanical work. Per 1,543·2 grains.

(b) Q, theoretical per 1,543·2 grains.

This table shews that blasting-gelatine is not perfectly detonated, even when stemmed in a tin tube of 0·98 inches and 1·57 inches. The complete detonation of this substance, that is to say, the complete combustion of the gases of the cotton by the oxygen of the dynamite, requires stronger vessels, capable of keeping the gases a longer time in mutual contact. It is probable that gelatine, in soft rocks of little resistance, only developes a part of its energy.

Bellite and pyroxyline-powder detonate completely in the tin tube of 0·98 inch and 1·57 inches; bellite detonates perfectly, even in a lead tube of 1·18 inches and 1·38 inches.

Mixtures of dynamite and sal-ammoniac detonate in the tin tube of 0·98 inch and 1·57 inches, nearly the same, as they detonate when unconfined. The decomposition of the sal-ammoniac is not effected or very partially so, even under comparatively favourable conditions. The speed of decomposition of the sal-ammoniac is too little.

Mixtures of dynamite and ammonia-alum, are similar.

Mixtures of 20 per cent. dynamite and 80 per cent. of nitrate of ammonia detonate perfectly in the tin tube of 0·98 inches and 1·57 inches.

Mixtures of cotton (= ·68) and nitrate of ammonia, are similar.

Effect produced by Explosives stemmed in a Shot-hole and Ignited with Fuse.—The explosives detonate by the action of the detonators; they may continue to burn, at least generally, when they are ignited by flame.

When this second method of decomposition happens, it may be the cause of special dangers in fiery mines. If it occurs unconfined, the fire-damp would be ignited, but it is rather difficult to understand how a similar accident could be produced in practice.

When the explosive is placed at the bottom of a shot-hole, it may be ignited by the action of the Bickford fuse, if that fuse comes in contact with the explosive before it fires the detonator.

These conditions have been reproduced, with a dynamite cartridge well stemmed in a tin tube of 0·98 inches and 1·57 inches; into this cartridge and right to the bottom is inserted a Bickford fuse, carrying at its end a detonator of 23 grains of fulminate. The fire-damp is ignited. This effect does not occur if detonator is not used. Doubtless the detonator has the effect of projecting outside, the already swollen tube, the flame which fills it entirely.

Safety, therefore, imperiously demands, as well as the useful employment of the explosive, that the Bickford fuse should never be in contact with the explosive.

Summary.—General Rule for the use of Explosives in a Fiery Mine.—This part of the studies of the Commission may be summarised by saying that explosives which do work are less dangerous than those which do no work, and that they are so much the less dangerous as they work better. All the conditions which tend to diminish the useful effect of the explosive, such as the absence of stemming or imperfect stemming, the space left behind the stemming or between the stemming and the stemming and the explosive, and contact between the Bickford fuse and the explosive, ought to be avoided with the utmost care.

CHAPTER IV.

METHOD OF FIRING SHOTS IN MINES.

Detonators Plugged and Unplugged—Difference of their Effects on the Ignition of Fire-damp.—The detonation of explosives necessitates the use of a detonator, which is usually formed of a small cylindrical vessel of copper or brass, generally containing fulminate of mercury, more or less mixed with other substances.

It was found, as already mentioned, that so-called plugged detonators, with 23 and even 31 grains of fulminate, do not ignite the fire-damp. Plugged detonators with 23 grains fulminate do not even ignite mixtures of air and coal-gas, but they do ignite mixtures of air and of hydrogen.

Plugged detonators containing 77 grains of fulminate ignite fire-damp.

With unplugged detonators, the charge of 23 grains of fulminate, will produce ignition of mixtures of air and of fire-damp.

The principal difference between the unplugged and the plugged detonators is that, in the latter, the fulminate placed at the bottom of the cylinder is almost covered by a small metallic bonnet, with an orifice at the top which exposes the fulminate and allows firing to be effected. Moreover, the thickness of the metal is greater, and the fulminate, being more compressed, has a greater density.

According to the principles whose correctness has been demonstrated above, the plugged detonators having a greater metallic mass and a greater density of charging, the gases resulting from the detonation of the fulminate, expend more energy, in the shape of mechanical work, before coming in contact with the external gas; they ought, therefore, as has been observed, with equal charges, to ignite gaseous mixtures with greater difficulty.

Moreover, if an unplugged detonator with 23 grains of fulminate, be lapped externally with contiguous spirals of fine copper wire, the mechanical work that the gases of the detonation must produce is increased, and it has been proved that, under these conditions, the detonation of the unplugged detonator no longer ignites the fire-damp mixture. This experiment is a new demonstration of the principles above stated.

Various Detonators.—It has been found that the detonators from Paulilles, those fired by electricity, as well as those fired by Bickford fuse, do not ignite fire-damp. The same may be said of the Abegg detonators, fired by electricity.

The Ruggieri and Scola (*) detonator does ignite the fire-damp mixture.

Dangers which Characterise the Bickford Fuse.—The detonation of the detonator can be caused by the Bickford fuse, and it has been ascertained that the combustion of this fuse can occur in the midst of a fire-damp mixture without igniting it, provided, be it well understood, that the end which is lighted be outside the imflammable mixture.

The dangers attendant on the use of this fuse are, however, very evident.

It is safe only when of good quality, and its safety depends on the perfection of its make, which it is impossible to control.

Another very serious cause of danger arises from the possibility of a mistake by the workman pushing the fuse too deeply into the cartridge, and thus putting it in direct contract with the explosive. Under these conditions the explosive, burning before detonation, may project the gases produced by the combustion, outside the hole and produce an ignition of fire-damp. This source of danger is so much the more grave, as the safety of the mine depends upon an operation performed by a workman and impossible to control. Without speaking of the inconvenience which results from lighting the end of the fuse, which can only be done at a point in the drift where the absence of fire-damp is well ascertained; it, therefore, seems desirable that the use of the Bickford fuse should be suppressed in fiery mines.

Use of Electricity.—Electricity, either tensional or in currents, may then be employed. Without entering into a profound discussion of the various means of electric ignition, the inconveniences of tensional electricity which may give off,

---

(*) The Ruggieri and Scola detonator is a kind of small rod formed of priming powder, which the fuse, by means of a small quantity of explosive, projects, from the unstemmed orifice of the shot-hole, upon the cartridge placed at the bottom.

on its circuit, sparks capable of igniting the fire-damp, and which can only be carried to a rather short distance, when the wires are not perfectly insulated, should be considered.

It seems, therefore, that, as regards safety at least, currents at low tension are preferable.

Detonating Strings.—It was proposed to replace the electric wire by a detonating string of nitro-cellulose, which would be made to explode by means of a plugged fulminate detonator placed outside the hole, and ignited either by electricity or a friction match, or even by a Bickford fuse, which would be much less dangerous, because then it could never come in contact with the explosive. At the same time, the inconvenience of stemming upon a detonator which explodes by percussion would be avoided, and that of having, after a miss-fire, a cartridge with its detonator at the bottom of the hole.

Unfortunately, it is certain that these strings, when of small diameter, do not cause with certainty the detonation of the less sensitive explosives such as mixtures of cellulose (low in NO_2), and nitrate of ammonia, pyroxyline powder, &c.

On the other hand, by increasing the diameter of the string, there is perhaps the risk of too much enlarging the pipe, which is formed by the string in the stemming, and which it widens on detonation. The gases resulting from the detonation of the explosive might escape by this orifice, and cause the ignition of the fire-damp mixture outside.

This idea has, therefore, been abandoned, at least until more complete experiments may have been made on this subject.

Friction Detonators.—Lieutenant-Colonel Lauer, of the Austrian Engineers, has recently proposed to fire explosives stemmed at the bottom of a shot-hole by a friction detonator. This detonator, sunk into the cartridge, is set in action by means of a metallic wire enclosed in a small tube embedded in the midst of the stemming.

This system is already exclusively employed in a number of Austrian mines, where it would appear to be giving satisfaction. As soon as a sufficient number of Colonel Lauer's detonators are available, experiments will be made upon them, and a report made to the Commission.

CHAPTER V.

CONCLUSIONS.

The conclusions warranted by the researches of the Commission are as follows :—

1. Blasting-powder, even fired in the midst of water, can ignite mixtures of fire-damp and air.

2. Most of the known explosives, detonating unconfined, are liable to ignite fire-damp mixtures ; dynamite, military or mining gun-cotton, particularly the latter, blasting-gelatine, gelatine-dynamite, and ammonia-dynamite of Paulilles are in this category.

3. It is possible, however, to find explosives which detonate at a temperature low enough not to provoke, at least in the great majority of instances, detonating unconfined, the ignition of fire-damp mixtures. Among the explosives tested by the Commission which realise these conditions, more or less perfectly, may be mentioned :—

(1) Intimate mixtures of 50 per cent. of dynamite with 50 per cent. of crystallised carbonate of soda ; sulphate of soda with 10 equivalents of water ; ammonia-alum ; or sal-ammoniac.

(2) The pyroxyline powder from Moulin-Blanc.

(3) The mixture of 20 per cent. of dynamite (75 per cent.) with 80 per cent. of nitrate of ammonia.

(4) The mixture of 20 per cent. of gun-cotton (= ·68 cubic inch of NO_2 per grain) and 80 per cent. of nitrate of ammonia.

(5) Bellite, the composition of which is not known with perfect certainty, and which, as yet, has undergone an insufficient number of tests.

(6) Favier explosive, made of about 90 per cent. of nitrate of ammonia, and 10 per cent. of mononitro-naphthalene, which appears likely to equal bellite as regards safety, but whose intermediate detonator, such as has been submitted to the Explosive Substances Commission, should be suppressed, and upon which further experiments should be made.

4. By reason of the complexity and the lack of certainty of the phenomena which may attend the detonation of unconfined explosives, it will always be prudent to avoid firing shots (even charged with one of the explosives considered the safest) at a point where the mixture of fire-damp and air may be inflammable. The choice of these explosives should be considered as considerably lessening the danger of explosion ; it should not be considered as absolutely suppressing it.

5. Explosives must always be used under the conditions which allow them to develope the maximum of useful work. Both economy and safety agree in the recommendation of this rule.

Consequently, the explosive must be carefully stemmed at the bottom of the shot-hole, which must be deep enough ; the leaving of an empty space either in front of or behind the cartridge, or on one side must be avoided ; contact must be avoided between the explosive and the Bickford fuse, if the detonator is fired by that means, the danger of which is besides serious enough to make it desirable to replace it by a safer means of firing.

The Commission had not to consider matters of management. It may be seen, however, that the preceding conclusions tend to the abandonment of blasting-powder in fiery mines, and even to throw suspicion on ordinary dynamite, blasting-gelatine, and ammonia-dynamite, as now manufactured ; blasting-gelatine appearing to be the most dangerous of all these substances.

The explosives which can best be recommended as regards safety are dual mixtures of an explosive such as dynamite, gun-cotton, or dinitro-benzol, with nitrate of ammonia. The mode of manufacturing these mixtures, the manner in which they can be protected from atmospheric moisture, and the greater or less duration of their resistance to this influence ought to be tested. It will also be necessary to test the useful effect of these mixtures in practical experiments, the manner in which they act in breaking down stone, and more particularly coal. The study of these questions will require experiments, most of which can only be made at the mine, and by the managers.

The Commission express the desire that the Government Powder Mills should manufacture a sufficient number of cartridges of these various explosive mixtures, to be distributed to those managers who would be willing to try them in a practical way.

The trials finished, there would remain the question of the manufacture on large scale. For some of the mixtures which appear to possess good enough guarantees of safety, such as gun-cotton and nitrate of ammonia, the Government Powder Mills have the monopoly of manufacture.

The mining industry, moreover, would only gain from the establishment of an active competition in the manufacture of the explosives, at present almost an actual monopoly. This advantage will be still greater when it is a question of mixtures, the comparative safety of which depends upon the exact proportion of the mixed substances, which is difficult to regulate.

The Commission, therefore, express the view that the Government Powder Mills should take measures to supply to the trade those mixtures based on gun-cotton recognised as advantageous as regards the safety of fiery mines.

5th July, 1888.

The President of the Sub-Commission and Reporter,
ER. MALLARD.

Adopted by the Commission at their sitting of the 5th July, 1888,
P. VIEILLE, Secretary. BERTHELOT, President.

TABLE OF EXPERIMENTS MADE AT THE SEVRAN-LIVRY POWDER MILL.

FROM NOVEMBER, 1887, TO JUNE, 1888.

NOTES.—I signifies that the gaseous mixture was ignited by the detonation of the explosive.
N signifies that there was no ignition of the gaseous mixture.
In the list of dates the numbers after the date itself show that the experiment was made with the first, second, or third gaseous mixture prepared on that day.

I. DETONATORS.

DATES.	Weight of Fulminate	Proportion of CH_4 in mixture.	Result of Experiment.	Remarks.
1. UNPLUGGED DETONATORS.				
	Grains.	Per cent.		
18 Nov. (1)	23·15	8·7	I	
23 Nov. (1)	23·15	8·7	I	
30 Nov. (2)	23·15	8·5	I	
9 Dec. (3)	23·15	8·7	I	
24 Apr. (1)	23·15	10·3	I	
2 May (2)	23·15	10·3	I	
11 May (1)	23·15	10·3	I	
2. UNPLUGGED DETONATORS LAPPED EXTERNALLY WITH COPPER WIRE.				
2 May (2)	23·15	10·3	N	
11 May (1)	23·15	10·3	N	
3. PLUGGED DETONATORS.				
23 Nov. (2)	3·86	8·7	N	
23 Nov. (2)	7·72	8·7	N	
23 Nov. (2)	15·43	8·7	N	
23 Nov. (2)	19·29	8·7	N	
29 Nov. (1)	23·15	8·5	N	
29 Nov. (1)	23·15	9·6	N	
17 Mar. (1)	23·15	10·3	N	
11 May (1)	23·15	10·3	N	
13 Nov. (2)	30·86	10·3	N	
15 Nov. (2)	54·01	10·7	N	One detonator of 23·15 grains in one of 30·86 grains.
10 Nov. (2)	69·45	10·3	N	Three detonators of 23·15 grains each.
16 May (2)	77·16	10·3	I	
30 May (2)	77·16	10·3	I	
4. PAULILLES DETONATORS.				
24 Apr. (1)	?	10·3	N	
24 Apr. (1)	?	10·3	N	

I.—DETONATORS—*Continued.*

DATES.	Weight of Fulminate	Proportion of CH_4 in mixture.	Result of Experiment.	Remarks.

5. ABEGG DETONATORS.

	Grains.	Per cent.		
9 Dec. (3)	?	8·7	N	
10 Mar. (3)	?	10·3	N	

6. RUGGIERI AND SCOLA DETONATORS.

23 May (1)	...	10·3	I	

7. BICKFORD FUSE.

20 Apr. (2)	...	10·3	N	Fuse 2 ft. long, burning in the gas, ignited outside, having at its end a detonator of 23·16 grains.
24 Apr. (1)	...	10·3	N	Fuse ignited outside, having at its end a Paulilles detonator.
2 May (2)	...	10·3	N	Fuse pushed into a cotton cartridge enclosed in a tube.
3 May (1)	...	10·3	N	do. do.
3 May (1)	...	10·3	N	do. do.
3 May (1)	...	10·3	N	Fuse pushed into dynamite enclosed in a tube.

II. UNCONFINED CARTRIDGES.

DATES.	Weight of Explosive.	Number and Size of Detonators.	Proportion of CH_4	Result of Test.	Remarks.

A. EXPLOSIVES ALREADY KNOWN.

1. No. 1 DYNAMITE (VONGES, 75 per cent. of nitro-glycerine).

	Grains.		Per cent.		
23 Dec. (3)	771·6	1 of 23·15 grains.	7·0	I	Cartridge wrapped in paper.
15 Feb. (1)	771·6	do.	7·0	I	do. do.
5 Dec. (2)	771·6	do.	8·5	I	do. do.
9 Dec. (2)	771·6	do.	8·7	I	do. do.
26 Dec. (2)	771·6	do.	8·7	I	do. do.
21 Feb. (1)	771·6	do.	10·3	I	do. do.
15 Mar. (2)	771·6	do.	10·3	I	Cartridge in lead tube 1·06 in. and 1·57 in., closed at one end and open at the other.
10 Mar. (3)	771·6	do.	10·3	I	Sides of cartridge covered with clay, ends exposed.
17 Mar. (1)	771·6	do.	10·3	I	Cartridge in lead tube 1·06 in. by 1·57. Ends closed by thin tamping of clay from ·4 in. to ·8 in.

2. No. 0. DYNAMITE (PAULILLES).

9 Feb. (3)	Grains. 771·6	1 of 23·15 grs.	Per cent. 6·1	I	

3. BLASTING-GELATINE (PAULILLES).

5 Dec. (1)	771·6	1 of 23·15 grs.	8·5	N	Detonation very doubtful.
Feb. (1)	771·6	do.	8·7	N	do. do.
26 Dec. (1)	771·6	do.	8·7	N	do. do.
10 Feb. (1)	771·6	do.	8·7	N	do. do.
18 Feb. (1)	771·6	do.	8·7	N	Detonation very doubtful. Pressure developed in boiler = ·39 in. of water.
12 Dec. (1)	771·6	do.	12·4	N	Detonation very doubtful.
12 Dec. (2)	771·6	do.	11·1	N	do. do.
15 Mar. (1)	771·6	2 of 38·58 grs.	7·0	I	Cartridge in lead tube of 1·06 in. and 1·57 in. and open at both ends.
12 Dec. (3)	771·6	1 of 23·15 grs.	10·3	I	Cartridge unconfined.

II.—UNCONFINED CARTRIDGES—*Continued.*

DATES.	Weight of Explosive.	Number and Size of Detonators.	Proportion of CH_4	Result of Test.	Remarks.

4. GELATINE-DYNAMITE (PAULILLES).

9 Dec. (3)	771·6	1 of 23·15 grs.	8·7	N	Detonation very doubtful.
28 Dec. (1)	771·6	do.	9·6	N	do. do.
12 Dec. (4)	771·6	do.	10·3	N	do. do.
12 Dec. (2)	771·6	do.	11·1	N	do. do.
12 Dec. (1)	771·6	do.	12·4	N	do. do.
13 Feb. (3)	771·6	1 of 30·86 grs.	8·7	N	do. do.
15 Feb. (1)	771·6	3 of 23·15 grs.	7·0	N	do. do.
15 Feb. (2)	771·6	do.	8·7	N	Detonation very doubtful. Pressure developed = ·39 in. of water.
13 Feb. (2)	771·6	1 of 30·86 grs.	10·3	I	

5. AMMONIA DYNAMITE (PAULILLES).

9 Feb. (3)	771·6	1 of 23·15 grs.	6·1	N	
9 Feb. (2)	771·6	do.	8·7	I	
9 Feb. (1)	771·6	do.	10·3	I	

6. MILITARY GUN-COTTON in thin brass cases.

28 Dec. (1)	432·1	1 of 23·15 grs.	7·0	N	
5 Dec. (2)	432·1	do.	8·5	N	
5 Dec. (1)	432·1	do.	8·5	I	

7. MINING GUN-COTTON, Cartridges wrapped in paper.

	Grains.		Per cent.		
23 Dec. (2)	463·0	1 of 23·15 grs.	6·1	I	
23 Dec. (1)	463·0	do.	7·0	I	
9 Dec. (1)	463·0	do.	8·7	I	
2 Dec. (2)	463·0	do.	8·7	I	
2 Dec. (1)	463·0	do.	8·7	I	
30 Nov. (1)	432·1	do.	9·6	I	
29 Nov. (2)	432·1	do.	9·6	I	
12 Dec. (2)	463·0	do.	11·1	I	
12 Dec. (1)	463·0	do.	12·4	I	
11 May (2)	463·0	do.	10·3	I	

8. GUN-COTTON (·68 cubic inch of NO_2 per grain).

4 June (4)	463·0	2 of 23·15 grs.	10·3	I	

II.—UNCONFINED CARTRIDGES—*Continued.*

9. PYROXYLINE POWDER (MOULIN-BLANC).
In rectangular cartridges, strongly compressed.

DATES.	Weight of Explosive.	Number and Size of Detonators.	Proportion of CH_4	Result of Test.	Remarks.
	Grains.		Per cent.		
9 May (2)	771·6	1 of 23·15 grs.	10·3	N	In a thin brass case.
9 May (2)	771·6	do.	10·3	N	Cartridge unconfined.
9 May (2)	771·6	do.	10·3	N	do.
11 May (2)	771·6	do.	10·3	N	do.
23 May (1)	771·6	do.	10·3	N	do.
23 May (1)	771·6	do.	10·3	N	do.
23 May (2)	771·6	do.	10·3	N	do.
1 June (1)	771·6	do.	10·3	N	do.
1 June (3)	771·6	do.	10·3	N	do.
1 June (3)	771·6	do.	10·3	N	do.
1 June (5)	771·6	do.	10·3	N	do.
4 June (2)	771·6	do.	10·3	N	do.
19 May (3)	771·6	do.	10·3	I	Cartridge unconfined. Temperature inside boiler 104° F.; weather oppressive.
10 May (4)	771·6	do.	10·3	I	do. do.

10. GUN-COTTON AND NITRATE OF BARIUM.

9 May (1)	463·0	1 of 23·15 grs.	10·3	I	Cartridge unconfined.

11. GUN-COTTON (WETTEREN) AND NITRATE OF BARIUM.

9 May (2)	?	1 of 23·15 grs.	10·3	I	

12. FAVIER EXPLOSIVE.

10 Mar. (1)	617·3	2 of 23·15 grains.	10·3	N	Cartridges made at Sevran with the mixture, as directed by Mr. Favier. Detonation very doubtful.
10 Mar. (2)	617·3	3 of 23·15 grains.	10·3	I	

13. HELLHOFFITE.

15 Mar. (2)	?	1 of 23·15 grains.	—	—	The cartridge did not detonate.

14. BELLITE.

10 Feb. (1)	771·6	1 of 23·15 grains.	8·7	N	Detonation very doubtful.
15 Feb. (2)	771·6	do.	8·7	N	Detonation very doubtful. Pressure developed = 1·38 in. of water.
30 May (1)	771·6	do.	10·3	N	Detonation very doubtful.
1 June (3)	771·6	do.	10·3	N	Detonation very doubtful. Explosives warmed to 104° F.
4 June (4)	771·6	2 of 23·15 grains.	10·3	N	Pressure developed = 9·45 in. of water. Temperature of gas in boiler = 95° F.
4 June (4)	771·6	do.	10·3	N	Pressure = 11·81 in. of water. Temperature in boiler = 95° F.

II.—UNCONFINED CARTRIDGES—*Continued.*

DATES.	Weight of Substance added to the Explosive in 100 parts of Mixture.	Weight of Explosive.	Number and Size of Detonators.	Proportion of CH_4	Result of Test.	Remarks.

B. VARIOUS MIXTURES.
a. MIXTURES WITH DYNAMITE BASE.
1. MIXTURES WITH CRYSTALLIZED CARBONATE OF SODA.

		Grains.		Per cent.		
27 Mar. (1)	Equal vols.	385·8	1 of 23·15 grs.	10·3	N	In a brass case.
27 Mar. (1)	50 Carb.	1,543·2	do.	10·3	N	do.

2. MIXTURES WITH CRYSTALLIZED SULPHATE OF SODA (with 10 equivalents of H_2O).

17 Mar. (2)	50 Sulph.	694·5	1 of 23·15 grs.	10·3	N	In a brass case.
17 Apr. (1)	33 Sulph.	694·5	do.	10·3	I	

3. MIXTURES OF DYNAMITE AND AMMONIA-ALUM.

24 Apr. (1)	50 Alum.	1,543·2	1 of 23·15 grs.	10·3	N	In a thin tin case.
11 May (3)	do.	1,543·2	do.	10·3	N	In a brass case.
24 Apr. (1)	33 Alum.	1,543·2	do.	10·3	N	do.
1 June (4)	do.	1,543·2	do.	10·3	N	do.
4 June (1)	do.	1,543·2	do.	10·3	I	
28 June (1)	25 Alum.	1,543·2	do.	10·3	I	do.

4. MIXTURES WITH SAL-AMMONIAC.

		Grains.		Per cent.		
20 Apr. (1)	50 Sal-Amm.	1,543·2	1 of 23·15 grs.	10·3	N	In a brass case.
24 Apr. (1)	do.	1,543·2	do.	10·3	N	In a tin case.
11 May (2)	do.	1,543·2	do.	10·3	N	In a brass case.
1 June (4)	40 Sal-Amm.	1,543·2	do.	10·3	N	do.
1 June (5)	do.	1,543·2	do.	10·3	N	In a brass case. Pressure = 19·68 in. of water.
4 June (2)	do.	1,543·2	do.	10·3	I	In a brass case.
1 June (1)	33 Sal-Amm.	1,543·2	do.	10·3	I	do.

5. MIXTURES WITH DUST OF COMBUSTIBLE MINERALS.

20 Apr. (3)	50 dust.	1,388·9	1 of 23·15 grs.	10·3	N	In brass case. Blanzy coal dust.
11 May (2)	do.	1·388·9	do.	10·3	N	In brass case. Blanzy coal dust.
30 May (2)	do.	1,388·9	do.	10·3	N	In brass case. Drocourt (P. de C.) coal dust.
30 May (2)	do.	1,388·9	do.	10·3	N	In brass case. Dourges (P. de C.) coal dust.
20 Apr. (3)	33 dust.	1,388·9	do.	10·3	N	In brass case. Blanzy coal dust.
1 May (3)	25 dust.	463·0	do.	10·3	N	In brass case. Blanzy coal dust.
19 May (1)	50 dust.	1,543·2	do.	10·3	I	In brass case. Lignite (brown coal) dust.

II.—UNCONFINED CARTRIDGES—*Continued.*

DATES.	Weight of Substance added to the Explosive in 100 parts of mixture.	Weight of Explosive.	Number and Size of Detonators.	Proportion of CH_4	Result of Test.	Remarks.
6. MIXTURES WITH NITRATE OF AMMONIA.						
		Grains.		Per cent		
4 June (2)	80 Nitrate.	1,543·2	1 of 23·15 grs.	10·3	N	In a brass case.
4 June (2)	do.	1,543·2	do.	10·3	N	do.
***b.* MIXTURES WITH GUN-COTTON BASE.** **1. MIXTURES OF SAL-AMMONIAC WITH MINING GUN-COTTON.**						
19 May (2)	25 Sal-Amm.	771·6	1 of 23·15 grs.	10·3	I	Unenclosed. Tem. in boiler 104°. Weather stormy.
23 May (1)	20 Sal-Amm.	964·5	do.	10·3	N	Unenclosed.
23 May (2)	12·5 Sal-Amm.	771·6	do.	10·3	I	do.
(2) MIXTURES WITH NITRATE OF AMMONIA. **α MILITARY GUN-COTTON (·81 CUBIC INCH OF NO_2 PER GRAIN.)**						
1 June (2)	70 Nitrate.	771·6	1 of 23·15 grs.	10·3	N	
1 June (2)	do.	771·6	do.	10·3	I	
1 June (5)	do.	771·6	do.	10·3	I	
4 June (3)	80 Nitrate.	771·6	do.	10·3	N	
4 June (3)	do.	771·6	do.	10·3	I	
β. MINING GUN-COTTON (·76 CUBIC INCH of NO_2 PER GRAIN) Cartridges probably damp.						
19 May (4)	50 Nitrate.	771·6	1 of 23·15 grs.	10·3	N	Detonation doubtful. Temperature of gas inside boiler = 104° F.
19 May (4)	do.	771·6	do.	10·3	I	do.
23 May (1)	do.	771·6	do.	10·3	N	Detonation doubtful.
23 May (1)	do.	771·6	do.	10·3	N	do.
30 May (2)	do.	771·6	2 of 23·15 grs.	10·3	N	do.
30 May (2)	do.	771·6	3 of 23·15 grs.	10·3	N	do.
γ. GUN-COTTON (·68 CUBIC INCH NO_2 PER GRAIN).						
1 June (3)	65 Nitrate.	771·6	1 of 23·15 grs.	10·3	I	
4 June (2)	80 Nitrate.	771·6	do.	10·3	N	Pressure developed inside boiler = 3·94 in. of water
4 June (2)	do.	771·6	do.	10·3	N	Pressure developed inside boiler = 7·87 in. of water
4 June (2)	do.	771·6	do.	10·3	N	Pressure developed inside boiler = 7·87 in. of water
4 June (2)	do.	771·6	do.	10·3	N	Pressure developed inside boiler = 7·87 in. of water
27 June (1)	do.	771·6	do.	10·3	N	Pressure developed inside boiler = 7·87 in. of water
27 June (1)	do.	771·6	do.	10·3	N	Pressure developed inside boiler = 7·87 in. of water
27 June (1)	do.	771·6	do.	10·3	N	Pressure developed inside boiler = 7·87 in. of water

III. ENCLOSED CARTRIDGES.

As a rule the cartridges are inserted in tubes closed at one end.

The explosive rests on a plug of clay 1·97 in. to 2·36 in. thick. It is stemmed with a tamping of clay 3·94 in. to 4·72 in. thick.

The proportion of CH_4 in the gaseous mixture is 10·3 per cent.

Dates.	Nature of Explosive.	Weight of Explosive.	Number and Size of Detonators.	Result of Experiment.	Nature of Tube.	Internal and External Diameters of Tube.	Remarks.
		Grs.				Inches.	
22 Feb. (1)	Dynamite (No. 1 Vonges) 75 % of nitro-glycerine	771·6	1 of 23·15 grs.	N	...	...	Cartridge covered with clay.
13 Mar. (3)		771·6	Detonating string.	I	...	...	
17 Mar. (2)		771·6	1 of 23·15 grs.	I	...	...	
2 May (1)	do.	771·6	do.	N	Tin	0·98 × 1·57	
11 May (2)	do.	771·6	do.	N	do.	do.	
12 Feb. (1)	do.	771·6	do.	N	do.	do.	
12 Apr. (1)	do.	771·6	do.	N	do.	do.	
15 Mar. (3)	do.	771·6	Detonating string.	N	Lead	1·06 × 1·57	
17 Mar. (2)	do.	771·6	1 of 23·15 grs.	N	do.	do.	
27 Mar. (1)	do.	771·6	do.	N	do.	do.	
27 Mar. (1)	do.	771·6	do.	N	do.	do.	
28 Mar. (1)	do.	771·6	do.	N	do.	1·26 × 1·65	
17 Apr. (2)	do.	771·6	do.	I	do.	1·18 × 1·57	
2 May (1)	do.	771·6	do.	I	do.	1·18 × 1·38	
6 Apr. (1)	do.	771·6	do.	I	Thick glass	...	
17 Apr. (2)	Dynamite 45 %	617·3	do.	N	Tin	0·98 × 1·57	
1 May (2)	Blasting-Gelatine (Paulilles)	771·6	do.	I	do.	do.	
17 Mar. (3)	do.	771·6	do.	I	Lead	1·06 × 1·57	
15 Mar. (2)	Gelatine-Dynamite (Paulilles)	771·6	do.	N	do.	do.	
15 Mar. (3)	do.	771·6	do.	N	do.	do.	
20 Apr. (2)	Ammonia Dynamite (Paulilles)	771·6	do.	N	Tin	0·98 × 1·57	
20 Apr. (3)	do.	771·6	do.	N	...	...	
20 Apr. (1)	Dynamite No. 2 (Paulilles)	771·6	do.	N	do.	0·98 × 1·77	
12 Apr. (2)	Dynamite No. 3 (Paulilles)	771·6	do.	N	do.	do.	
2 May (2)	Mining Gun-cotton.	925·9	do.	N	Lead	1·26 × 1·65	
2 May (2)	do.	771·6	do.	N	do.	1·18 × 1·38	
9 May (2)	do.	463·0	do.	N	do.	do.	
11 May (2)	do.	463·0	do.	N	do.	do.	
28 Dec. (1)	do.	463·0	do.	N	Cartridge in hole drilled in block of wood.		

III.—ENCLOSED CARTRIDGES—*Continued.*

Dates.	Nature of Explosive.	Weight of Explosive.	Number and Size of Detonators.	Result of Experiment.	Nature of Tube.	Internal and External Diameters of Tube.	Remarks.
		Grs.				Inches.	
16 May (1)	Bellite	771·6	1 of 23·15 grs.	N	Lead	1·18 × 1·38	Pressure = 15·75 in. of water (about).
6 Apr. (2)	Favier Explosive	925·9	do.	N	do.	1·06 × 1·57	Detonation very doubtful.
6 Apr. (2)	do.	925·9	do.	N	Tin	0·98 × 1·57	do.
1 May (3)	do.	925·9	do.	N	do.	do.	do.
14 Apr. (1)	do.	925·9	1 of 30·86 grs.	N	Lead	1·18 × 1·57	do.
14 Apr. (1)	do.	925·9	1 of 77·16 grs.	N	do.	do.	Detonation very doubtful. Pressure = about 4·72 in. of water.
9 May (2)	Gun-cotton, with 10 °/o of Paraffin	540·1	1 of 23·15 grs.	N	Tin	0·98 × 1·57	Pressure about 7·87 in. of water.
9 May (1)	Gun-cotton, with Nitrate of Barium (Moulin-Blanc)	463·0	do.	N	Lead	1·18 × 1·38	

Experiments on the Influence of the Density of Charging.

Dates.	Nature of Explosive.	Weight of Explosive.	Number and Size of Detonators.	Result of Experiment.	Nature of Tube.	Internal and External Diameters of Tube.	Remarks.
27 Mar. (1)	Dynamite No. 1 (Vonges)	771·6	1 of 23·15 grs.	N	Lead	1·06 × 1·57	
27 Mar. (1)	do.	463·0	do.	I	do.	do.	Dynamite in internal glass tube.
12 Mar. (3)	do.	463·0	do.	I	do.	do.	do.
14 Mar. (3)	do.	463·0	do.	I	do.	do.	do.
11 May (2)	do.	463·0	do.	N	Tin	0·98 × 1·57	do.
11 May (3)	do.	463·0	do.	N	do.	do.	do.
1 May (1)	do.	771·6	do.	I	Lead	1·26 × 1·65	Dynamite not rammed.
24 Apr. (1)	do.	771·6	do.	N	do.	do.	Dynamite rammed.
17 Mar. (2)	do.	463·0	do.	I	do.	1·18 × 1·57	Round tube.
17 Mar. (2)	do.	463·0	do.	N	do.	do.	Flattened tube.

Experiments on Ignition of Explosives by Fuse.

Dates.	Nature of Explosive.	Weight of Explosive.	Number and Size of Detonators.	Result of Experiment.	Nature of Tube.	Internal and External Diameters of Tube.	Remarks.
15 Mar. (2)	Dynamite No. 1 (Vonges)	771·6	Wire heated red by electric current	N	Lead	1·06 × 1·57	Ignition by red-hot wire.
15 Mar. (2)	do.	771·6	do.	N	do.	do.	do.
2 May (2)	do.	771·6	Bickford fuse pushed into cartridge	N	Tin	0·98 × 1·57	
20 Mar. (2)	do.	771·6	Bickford fuse thrust into cartridge carrying 1 detonator of 23·15 grs. at its end.	I	do.	do.	

III. ENCLOSED CARTRIDGES—*Continued.*

Experiments on Ignition of Explosives by Fuse—*Continued.*

Dates.	Nature of Explosive.	Weight of Explosive.	Number and Size of Detonators.	Result of Experiment.	Nature of Tube.	Internal and External Diameters of Tube.	Remarks.
		Grs.				Inches.	
3 May (2)	Mining Gun-cotton.	231·5	Bickford fuse	I	Cotton placed on the fuse without covering.		
3 May (2)	do.	771·6	do.	N	Tin	0·98 × 1·57	
3 May (2)	do.	771·6	do.	N	do.	do.	
2 May (2)	do.	771·6	do.	N	do.	do.	
2 May (2)	do.	925·9	Bickford fuse thrust into cartridge carrying 1 detonator of 23·15 grs. at its end.	N	do.	do.	
4 May	do.	Cotton placed unconfined, at the bottom of lead tube, and ignited by the Bickford fuse, burnt without emitting flame.					
4 May	do.	In the same experiment the cotton burnt with flame.					

IV. EXPERIMENTS ON THE SETTLE CARTRIDGES.

The explosive cartridges are placed in the midst of an impermeable paper tube filled with water.

15 Mar. (3)	Blasting Powder (in round hole)	370·4	1 of 23·15 grs.	I	
9 Dec. (2)	Dynamite No. 1 (Vonges)	771·6	do.	N	
27 June (1)	do.	771·6	do.	I	

V. EXPERIMENTS WITH COAL DUSTS.

14 Apr. (3)	Dynamite No. 1 (Vonges)	771·6	1 of 23·15 grs.	N	Cartridge in tin tube 0·98 in. by 1·57 in. Stemmed with 5·12 inches of Blanzy coal dust.
17 Apr. (1)	do.	771·6	do.	N	do.
1 June (5)	Pyroxyline Powder	771·6	do.	N	Cartridge placed inside a Settle bag filled with Blanzy coal dust.
24 Apr.	Dynamite No. 1 (Vonges)	A cartridge of 1,543·2 grains of Dynamite No. 1, enveloped with coal dust, exploding unconfined, by a detonator of 23·15 grains, did not ignite the dust.			
24 Apr.	do.	A cartridge of 1,543·2 grains of Dynamite No. 1, enveloped with coal dust, and kindled unconfined with Bickford fuse, ignited the dust.			
24 Apr.	do.	A cartridge of 771·6 grains, placed in a Settle bag filled with coal dust, and exploded by a detonator of 23·15 grains, gives exactly the same pressure (in inches of water) as a naked dynamite cartridge of the same weight.			

VI. EXPERIMENTS ON DETONATION IN THE CLOSED BOILER.

Dates.	Nature of Explosive.	Method of using the Explosive.	Weight of Explosive.	Number and Size of Detonators.	Initial pressure developed by the Detonation Inches of water.
			Grs.		
28 April	Dynamite No. 1 (Vonges)	Exposed cartridge	771·6	1 of 23·15 grs.	32·68
28 April	do.	Stemmed in tin tube 0·98 in. by 1·57 in.	771·6	do.	20·67
28 April	do.	Stemmed in lead tube 1·26 in. by 1·65 in.	771·6	do.	18·11
8 June	do.	Stemmed in lead tube 1·18 in. by 1·38 in.	771·6	do.	22·24
28 April	do.	In thin glass tube ·55 in. ext. diam.	401·2	do.	16·54
28 April	do.	Thin glass tube inside tin tube 0·98 in. by 1·57 in.	401·2	do.	12·99
25 May	Blasting gelatine (Paulilles)	Exposed.	617·3	do.	22·05
25 May	do.	do.	771·6	do.	27·17
25 May	do.	do.	771·6	do.	27·56
25 May	do.	In tin tube 0·98 in. by 1·57 in.	771·6	do.	24·41
25 May	Military Gun-cotton	Exposed.	771·6	do.	28·35
25 May	do.	do.	771·6	do.	28·35
25 May	Mining Gun-cotton	do.	771·6	do.	...
25 May	do.	do.	771·6	do.	58·27(?)
4 June	Bellite	do.	771·6	2 of 23·15 grs.	9·84
8 June	do.	do.	771·6	do.	13·39
8 June	do.	do.	771·6	1 of 23·15 grs.	11·02
8 June	do.	In tin tube 0·98 in. by 1·57 in.	771·6	2 of 23·15 grs.	20·08
4 June	do.	In lead tube 1·18 in. by 1·38 in.	771·6	1 of 23·15 grs.	18·50
9 May	Pyroxyline powder	Exposed.	1003·1	do.	24·02
25 May	do.	do.	771·6	do.	20·47
25 May	do.	do.	771·6	do.	17·52
8 June	do.	do.	771·6	do.	23·62
8 June	do.	In tin tube 0·98 in. by 1·57 in.	771·6	do.	18·50
28 May	Cotton with nitrate of barium	Exposed.	771·6	do.	27·56
8 June	Cotton and nitrate soda in equal parts	do.	771·6	do.	20·47
8 June	80 Military cotton 70 Nitrate of ammonia	do.	771·6	do.	18·11
18 June	90 Cotton (= ·68)	do.	463·0	do.	37·01
18 June	10 Nitrate of ammonia	In tin tube 0·98 in. by 1·57 in.	463·0	do.	9·05
23 June	80 Cotton(= ·68)	Exposed.	463·0	do.	24·80
23 June	20 Nitrate of ammonia	In tin tube 0·98 in. by 1·57 in.	463·0	do.	11·02

VI. EXPERIMENTS ON DETONATION IN THE CLOSED BOILER—*continued.*

Dates.	Nature of Explosive.	Method of using the Explosive.	Weight of Explosive.	Number and size of Detonators.	Initial pressure developed by the Detonation. Inches of Water.
			Grs.		
23 June	60 Cotton (= ·68)	Exposed.	463·0	1 of 23·15 grs.	13·78
23 June	40 Nitrate of ammonia	In tin tube 0·98 in. by 1·57 in.	463·0	do.	11·81
23 June	35 Cotton (= ·68) 65 Nitrate of ammonia	Exposed.	771·6	do.	16·93
9 June	25 Cotton (= ·68) 75 Nitrate of ammonia	Exposed.	771·6	2 of 23·15 grs.	16·14
9 June	67 Dynamite	Exposed.	771·6	1 of 23·15 grs.	20·87
9 June	33 Sal-ammoniac	In tin tube 0·98 in. by 1·57 in.	771·6	do.	16·54
9 June	60 Dynamite	Exposed.	771·6	do.	17·32
9 June	40 Sal-ammoniac	In tin tube 0·98 in. by 1·57 in.	771·6	do.	14·57
9 June	50 Dynamite	Exposed.	771·6	do.	16·54
9 June	50 Sal-ammoniac	In tin tube 0·98 in. by 1·57 in.	771·6	do.	14·57
9 June	67 Dynamite	Exposed.	771·6	do.	17·52
9 June	33 Ammonia-alum	In tin tube 0·98 in. by 1·57 in.	771·6	do.	14·96
18 May	20 Dynamite	Exposed.	771·6	do.	9·45
18 May	80 Nitrate of ammonia	In tin tube 0·98 in. by 1·57 in.	771·6	do.	11·02

NOTE A.

ON THE CALCULATION OF THE TEMPERATURES OF DETONATION AND THE POWER OF EXPLOSIVES.

By Messrs. Mallard and Le Chatelier.

THEORETICAL CALCULATION OF THE TEMPERATURE OF DETONATION.

If C is the specific heat under constant volume averaged between 0° and $t°$ of the gaseous products of the detonation of a certain weight of an explosive; if Q is the heat of decomposition corresponding to that weight, and to the mode of decomposition realised on detonation, the temperature t is given by the formula,

$$C\,t = Q. \qquad (1)$$

The specific heat C is not constant at all temperatures as has been shewn by the experiments of Messrs. Berthelot and Vieille (*), and our own (†).

If it be assumed that the value of C, at any temperature, is represented by a linear expression

$$C = a + b\,t, \qquad (2)$$

the preceding equation becomes

$$a\,t + b\,t^2 = Q.$$

To ascertain t; a, b, and Q, must be ascertained, which supposes that the law of decomposition is known. This hypothesis being realised, the numerous researches of Messrs. Berthelot, Sarrau, and Vieille will determine Q. As regards a and b, the decomposition of the explosives usually producing condensible gases such as CO_2 and H_2O, and non-condensible or perfect gases, such as CO, HCl, and the elementary gases; they can be deduced from the experiments, given in the memoir already quoted from the specific molecular heats of these gases, under constant volume and the mean temperature between 0° and $t°$. These expressions are in little calories (gramme-degree C).

For CO_2 (‡) ... ... $C = 6{\cdot}26 + 0{\cdot}0037\,t$,
For H_2O ... ... $C = 5{\cdot}61 + 0{\cdot}0033\,t$,
For the perfect gases ... ... $C = 4{\cdot}80 + 0{\cdot}0006\,t$.

If the equivalent weight S′ of the explosive is decomposed according to the formula

$$\alpha\,CO_2 + \gamma\,H_2O + \lambda\,P$$

P representing one molecule of a perfect gas, the co-efficients a and b of equation (2) will be respectively

$$a = 6{\cdot}26\,\alpha + 5{\cdot}61\,\beta + 4{\cdot}8\,\lambda,$$
$$b = 0{\cdot}0037\,\alpha + 0{\cdot}0033\,\beta + 0{\cdot}0006\,\lambda;$$

(*) Comptes Rendus, volume 98 (1884).

(†) Comptes Rendus, volume 92 (1882), and Ann. des mines, 8th series, volume 4 (1883).

(‡) Different expressions all giving the same value at 2,000 degs. (C) have been proposed for the specific heat of carbonic acid. Preference has been given to the linear expression which leads to the simplest calculations.

and if Q is the heat of decomposition of the weight ω, the temperature t will be found by the formula

$$t = \frac{-a + \sqrt{a^2 + 4\,b\,Q}}{2\,b}. \tag{3}$$

FORMULA OF CLAUSIUS.—CO-VOLUMES.

Clausius shewed that the pressure P, the volume V, and the absolute temperature T, of a gas which occupies the volume v_0 under the pressure p_0 at the absolute temperature 273 degs. (C), may be connected by the formula

$$\left[\frac{P}{p_0} + \frac{c}{T\left(\frac{V}{v_0} + \beta\right)^2}\right]\left(\frac{V}{v_0} - u\right) = \frac{T}{273},$$

which, with the very high temperatures and pressures now being considered, can be materially reduced, provided that $\frac{V}{v_0}$ be not too small, to

$$\frac{P}{p_0}\left(\frac{V}{v_0} - u\right) = \frac{T}{273}. \tag{1}$$

The co-volume is obtained for a very small number of gases, by the mathematical deductions which Mr. Sarrau has drawn from the experiments of Mr. Amagat (*). He obtained the following values :—

Hydrogen	0·000887
Nitrogen	0·001359
Oxygen	0·000890
Carbonic acid	0·000866
Marsh gas	0·001091
Ethylene	0·000967

It is remarkable that with gases so different in all their properties as hydrogen and carbonic acid for example, the values of u are so closely approximate. This naturally leads to the conclusion, as Mr. Bouty remarks (†) that the co-volumes of all the gases are identical. Indeed the co-efficient u is difficult enough to calculate, owing to the numerous experiments. The best proof is that Mr. Sarrau, using the experiments of Mr. Amagat, found for carbonic acid u = ·000866, and later when he took into account the experiments of Regnault on saturated steam, and of Messrs. Cailletet and Hautefeuille on the density of liquid carbonic acid, he has admitted u = 0·00115 (‡) which approximates but on the opposite side to the average 0·00101 of the six values of u for different gases deduced from the experiments of Mr. Amagat.

Doubtless it will not be far from the truth to assume that u has the same value for all gases ; and to take that value as equal to 0·001. This assumption is adopted in the following calculations.

CALCULATION OF THE EXPLOSIVE FORCE.

According to formula (1)—

$$P\,(V - u\,v_0) = \frac{1{\cdot}033\,v_0\,T}{273}, \tag{2}$$

P being expressed in kilogrammes per square centimetre.

(*) Comptes Rendus, volume 94, pp. 639, 718, 845 (1882).

(†) Jamin and Bouty, Cours de Physique, Complement, p. 103.

(‡) Comptes Rendus, volume 101 p. 1,145 (1885).

If the gas considered possesses the weight ω, its density Δ will be, $\Delta = \frac{\omega}{V}$, which gives

$$V = \frac{\omega}{\Delta}.$$

In the experiments on the pressures developed by explosives, Δ has been called the density of charging.

Introducing this value of V into (2) it becomes—

$$P\left(\frac{\omega}{\Delta} - u\,v_0\right) = \frac{1{\cdot}033\ v_0\ T}{273},$$

or

$$P = \frac{\frac{1{\cdot}033\ v_0\ T}{273\ \omega\ v}\Delta}{1 - \frac{u}{\omega}{}^{0}\Delta}$$

or, lastly,

$$P = \frac{f\,\Delta}{1 - \alpha\,\Delta}, \qquad (3)$$

supposing

$$f = \frac{1{\cdot}033\ v_0\ T}{273\ \omega}, \qquad (4)$$

$$\alpha = \frac{u\ v_0}{\omega}. \qquad (5)$$

The two co-efficients f and α are characteristics of each explosive; or in simpler terms, f is the explosive force of the explosive, and α is its co-volume.

MODE OF DECOMPOSITION OF AN EXPLOSIVE.

The mode of decomposition of an explosive, under the influence of detonation, is only known with certainty when this explosive contains enough oxygen to completely burn off the combustible elements C and H, which enter into its composition. The following are included in this class; nitro-glycerine $C_3H_5N_3O_9$, nitromannite $C_6H_8N_6O_{18}$, nitrate of ammonia $N_2O_3H_4$, and certain mixtures formed of two substances, the oxygen in excess in one of which is sufficient to completely burn the carbon and hydrogen of the other; such as the mixture of endecanitric cotton and nitrate of ammonia $C_{24}H_{29}N_{11}O_{42} + 20{\cdot}5\ N_2O_3H_4$. It is sufficient then to admit that the explosion produces the complete decomposition of the two substances, and that the subsequent reaction lead to the complete combustion of the dual explosive. These assumptions will be found generally correct, at least in the case of confined explosion.

When the explosive does not contain enough oxygen for its complete combustion, but still contains more of it than the quantity required for the combustion of C to the state of CO, it may be assumed that after detonation it only forms oxygen compounds, that all the carbon burns to CO, and that there is a certain division of the remaining oxygen between the CO and hydrogen.

The consequences which this hypothesis entails will now be examined.

If the explosive is represented by the formula $C_p\,H_{2q}\,O_r\,N_{2s}$, the law of its decomposition will be expressed in a general manner by

$$\alpha\,CO_2 + \beta\,CO + \gamma\,H_2O + \delta\,H_2 + \varepsilon\,N_2.$$

The following equations may be then admitted :—

$$\alpha + \beta = p,$$
$$\gamma + \delta = q,$$
$$2\,\alpha + \beta + \gamma = r;$$

hence

$$\alpha = r - p - q + \delta,$$
$$\beta = 2\,p + q - r - \delta,$$
$$\gamma = q - \delta;$$

whence it may be concluded :—

1. That the volume of the gases formed at 0° is constant, whatever may be the mode of decomposition, and equal to

$$v = (p + q + s) \times 22{\cdot}32 \text{ litres};$$

2. That the sum of the volumes of the perfect gases CO, H_2, N_2, is also constant, and equal to

$$(2\,p + q - r + s) \times 22{\cdot}32 \text{ litres};$$

3. That the quantity of heat at a constant volume Q_g (water gaseous) disengaged by the decomposition, calling F the heat of the formation of the substance from its elements, is

$$Q_g = 68{\cdot}2\,r - 41{\cdot}9\,p - 9{\cdot}5\,q + 10\,\delta + 0{\cdot}54\,s - F,$$

or, A being a constant independent of the mode of decomposition

$$Q_g = A + 10\,\delta.$$

The heat of decomposition (water liquid) is

$$Q_l = A - 0{\cdot}8\,\delta,$$

almost independent of δ, that is to say, of the mode of decomposition.

As δ cannot be negative, there is a maximum value of δ, which is the least of the two quantities q and $2\,p + q - r$, and a minimum value, which is either zero or $r - p - q$, if that expression is negative.

In the absence of exact experiments almost impossible to make, on account of the reactions put into play during the cooling, the variable δ may be assumed to have an average value between the maximum and minimum. Thus the mode of decomposition would be fixed.

All these preceding remarks rest on the hypothesis that the products of decomposition are simply the products of oxidation, and that there is no formation, during the detonation, of hydro-carbons, such as marsh gas CH_4, acetylene C_2H_2, etc., or any other compound.

Messrs. Sarrau and Vieille, in their profound researches on the decomposition of explosives (*), have indeed found that the gases remaining within the bomb, after the detonation of endecanitric cotton, are almost exclusively formed of oxides, for densities of charging, varying from ·0098 to ·3; fire-damp appeared only in extremely small quantity for a density of charging of ·3.

They admit, that for the usual densities of charging, the decomposition of endecanitric cotton should be, according to the formula

$$12\,CO_2 + 12\,CO + 6\,H_2O + 8{\cdot}5\,H_2 + 5{\cdot}5\,N_2.$$

On the other hand, they have found that for cottons less nitrated, there are found in the products of decomposition after the explosion, notable quantities of marsh gas, and even, with cotton of three equivalents of nitrogen (and 17 equivalents of hydrogen), cyanogen and ammonia.

Unfortunately these results, interesting as they may be, do not give with any certainty what is important to be known, that is to say, the composition of the gases at the moment of explosion, whose composition has only to be taken into account in calculating the heat of decomposition, the temperature of decomposition, and the co-efficients f and α.

(*) Memorial des poudres et saltpêtres Volume II. p. 126.

Indeed, the analyses can only be made after cooling, that is to say, at a moment when the complex ulterior reactions may have modified the nature of the products, more or less materially.

In the absence of any positive indications, those which result from the hypotheses just mentioned, and which do not appear to be far removed from reality, at least for highly nitrated cottons, picric acid, &c., may be adopted.

MODE OF DECOMPOSITION OF NITRIC COTTON.

It will be by no means useless to examine more closely the special application of these hypotheses to nitric cottons, on account of the importance of these explosives.

The composition of any nitric cotton may be represented by

$$C_{24}\,H_{40-n}\,N_n\,\;O_{20+2n}.$$

The maximum value of *n* will be 12; in practice *n* does not surpass 11.

Usually gun-cottons are classified according to the volume (in cubic centimetres) of nitrogen di-oxide given off per gramme, in the analysis by the Schlœsing process. The following is the relation between this volume and the number *n* of the preceding formula.

		n	Volume of NO_2 in c.c.
Endecanitric	Cotton	11	214
Decanitric	do.	10	203
Nononitric	do.	9	190
Octonicric	do.	8	178
Heptanitric	do.	7	162
Hexanitric	do.	6	146
Pentanitric	do.	5	128
Tetranitric	do.	4	108

In these calculations use has been made of the experimental results given by Messrs. Sarrau and Vieille for the combustion of endecanitric cotton. They found that with a charging density of 0·023 and the formula of decomposition being

$$15\,CO + 9\,CO_2 + 5{\cdot}5\,H_2 + 9\,H_2O + 5{\cdot}5\,N_2,$$

the reaction disengages 1,230 calories (liquid water), which gives for the heat of formation of gun-cotton, from its gaseous elements

$$F = +\,624.$$

Mr. Berthelot, on the other hand, has found, by fixing 11 equivalents of nitric acid to the cotton, according to the formula

$$C_{24}\,H_{40}\,O_{20} + 11\,NO_3\,H - 11\,H_2O,$$

it gives off a quantity of heat equal to 125·4. That gives for the formation heat (A) of cotton $C_{24}\,H_{40}\,O_{20}$,

$$A + 11 \times 46{\cdot}1 - 11 \times 69 + 125{\cdot}4 = 624,$$

whence $$A = 800.$$

The heat of formation of a cotton containing *n* equivalents of nitrogen will be

$$F_n = 800 + 41{\cdot}6n - 69n + 11{\cdot}4n,$$

or $$F_n = 800 - 16n.$$

Nevertheless, it must be remarked that these numbers do not agree with the figures found two years ago, by Messrs. Berthelot and Vieille, for the heat of formation of cellulose, by the reliable method of combustion in oxygen. They found for $C_6\,H_{10}\,O_5 = 162$ grammes, $A = 227{\cdot}2$, whence it may be calculated for $C_{24}\,H_{40}\,O_{20}$, $A = 908$ instead of 800. It may also be deduced that the heat of formation of endecanitric cotton is 732 instead of 624.

Only new experiments can cause this discordance to disappear, and the cause cannot be sought in an error in the analysis of the products of the decomposition of endecanitric cellulose, under a density of charging of 0·023. The quantity of heat Q (water liquid) corresponding to a simple oxidation of the carbon and of the oxygen may be easily found by the following equation :—

$$\alpha\,CO_2 + \beta\,CO + \gamma\,H_2O + \delta\,H_2 + \varepsilon\,N_2\,;$$

$$Q = 1{,}858{\cdot}4 - 0{\cdot}8\,\delta - F.$$

If $Q = 1{,}230$, and $F = 732$, it becomes

$$1{,}858{\cdot}4 - 0{\cdot}8\,\delta = 1{,}962,$$

an impossible equation, whatever δ may be. It will, therefore, be necessary to assume another reaction, such as a combination of carbon with hydrogen, which has not been ascertained by observation.

However this may be, if the numbers of Messrs. Sarrau and Vieille be adopted, as well as the heat of substitution of nitric acid given by Mr. Berthelot; if the exclusive formation of oxidised products, and a formula of decomposition a mean between those which correspond to the minimum and maximum of free hydrogen be adopted, the formula of decomposition of a cellulose containing n equivalents of nitrogen may be assumed to be

$$\alpha\,CO_2 + \beta\,CO + \gamma\,H_2O + \delta\,H_2 + \frac{n}{2}N_2,$$

when

$$\alpha = 24 + \frac{5n}{2} + \delta,$$

$$\beta = 48 - \frac{5n}{2} - \delta,$$

$$\gamma = 20 - \frac{n}{2} - \delta.$$

The heat of decomposition under constant volume Q (water gaseous) is

$$Q = 157{\cdot}4n - 631 + 10\,\delta.$$

The volume V of the gases supplied by the reaction is constant, whatever n and δ may be, and is equal to

$$V = 44 \times 22{\cdot}32.$$

TABLE OF THE TEMPERATURES OF DETONATION AND EXPLOSIVE FORCES OF VARIOUS EXPLOSIVES.

The following table has been calculated, starting with the assumptions and hypothesis, which have just been explained.

The factors have been constantly designated as follows :—

Q, the heat disengaged by the decomposition of the equivalent, the water being supposed gaseous; expressed in large calorics (kilogramme - degree C);

Q_k, the same heat for one kilogramme;

F, the heat of combination of the equivalent from the elements;

ω, the weight, in kilogrammes, of the portion of the equivalent, reduced to gases by the detonation;

ω', the total weight of the explosive;

v_0, the volume, in litres, of the gases formed by the detonation, reduced to 0°C and 760 mm. pressure;

t, the temperature of detonation;

Δ', the apparent density of charging, *i.e.*, the ratio $\frac{\omega'}{V'}$, between the weight of the equivalent and the volume that the internal tube would have, if the charge which it contains were one equivalent;

Δ, the actual density of charging, *i.e.*, the ratio between the weight ω, of the gases formed, and the volume V occupied by these gases in the internal tube. If v is the volume of the solid matters, entering into the composition of the explosive, or formed by its detonation, then

$$\Delta = \frac{\omega}{\frac{\omega'}{\Delta'} - v} ;$$

P, the pressure in kilogrammes per square centimetre, produced by the decomposition of the explosive in a closed vessel, under the apparent density of charging Δ (*) ;

,, the force of the explosive given by the equation

$$f = \frac{1{\cdot}033\ v_0\ (t + 273)}{273\ \omega} ;$$

α, the co-volume represented by the expression $\frac{u\ v_0}{\omega}$, in which u is assumed constant, and = 0·001.

Q	Q_k	t	f	α	Δ′	P	$\frac{P}{\Delta}$

A.—SIMPLE EXPLOSIVES.

I.—DYNAMITE (75 PER CENT).

$$2\ C_3H_5N_3O_9 = 6\ CO_2 + 5\ H_2O + O + 3\ N_2,\ \omega = 454,\quad \omega' = 605.$$

671·2	1,109	2,940°	8,490	0·71	0·3	2,279 (†)	—

II.—NITRATE OF AMMONIA.

$$N_2H_4O_3 = N_2 + O + 2\ H_2O,\quad \omega = 80.$$

30·4	380	1,130°	5,180	0·976	0·2(‡) 0·3 0·4	1,376 2,319 3,560	6,880 7,730 8,900

III.—PICRIC ACID.

$$2\ C_6H_3N_3O_7 = CO_2 + H_2O + 11\ CO + 2\ H_2 + 3\ N_2,\quad \omega = 458.$$

347·5 (‖)	759	2,620°	9,600	0·877	0·1 0·2 0·3 0·4	927 (§) 1,744 3,549, 3,500, 3,510, 3,456 (Average 3,504) 5,467	—

(*) These experimental figures are published in the experiments of Messrs. Sarrau and Vieille.

(†) Sarrau and Vieille.—Memoire sur les manometres à écrasement (Memorial des poudres et saltpêtres, Vol. I., page 415). The movement 6·50 observed with a piston of four kilogrammes has been taken, thence P has been deduced by the formula $P = 541 + 535\frac{s}{2}$

(‡) Report on the Favier explosive made to the Explosive Substances Commission, by Mr. Vieille 7th July, 1887.

(‖) Deduced from the heat of formation F = + 98·2.

(§) These figures have been supplied by Messrs. Sarrau and Vieille ; they have been only imperfectly published in the *Comptes Rendus*, Vol. IV., page 1,223, (1887).

Q	Q_k	t	f	α	Δ'	P	$\frac{P}{\Delta}$

IV.—Gun-Cottons.

1.—Endecanitric Cotton.

$C_{24}H_{29}N_{11}O_{42} = 10{\cdot}75\,CO_2 + 13{\cdot}25\,CO + 7{\cdot}25\,H_2O + 7{\cdot}25\,H_2 + 5{\cdot}5\,N_2,\ \omega = 1{,}143.$

1,172·3	1,026	2,650°	9,490	0·86	—	—	—

By the formula of Messrs. Sarrau and Vieille

$12\,CO_2 + 12\,CO + 6\,H_2O + 8{\cdot}5\,H_2 + 5{\cdot}5\,N_2.$

1,184·8	1,037	2,660°	9,530	0·86	0·1 (*) 0·2 0 3 0·4	942 2,039 3,927 5,430	9,420 10,190 13,090 13,570

2.—Octonitric Cotton.

$C_{24}H_{32}N_8O_{36} = 6\,CO_2 + 18\,CO + 6\,H_2O + 10\,H_2 + 4\,N_2,\ \omega = 1{,}003.$

727·6	722	2,064°	8,630	0·974	—	—	—

V.—Nitromannite.

$C_6H_8N_6O_{18} = 6\,CO_2 + 4\,H_2O + 3\,N_2 + O_2,\qquad \omega = 452$ grammes.

55·4	1,450	3,250°	9,210	0·691	0·1 0·2	1,481 (†) 2,585	—

B.—DUAL EXPLOSIVES.

I.—Bellite = 80 Nitrate of Ammonia + 20 Dinitro-Benzol.

The formula 0·175 binitro-benzine + 0·825 nitrate has been adopted, which allows sufficient oxygen for complete combustion.

$C_6H_4(NO_2)_2 + 10\,N_2H_4O_3 = 11\,N_2 + 22\,H_2O + 6\,CO_2.\ \omega = 968$ grammes.

973·8	1,006	2,190°	8,000	0·869	—	—	—

II.—The Favier Explosive.

$21{\cdot}5\,N_2H_4O_3 + C_{10}H_7NO_2,\ \omega = 1{,}893.$

1,831·7	6	2,120°	8,400	0·926	0·2	1,886 2,253 } 2,051 2,014	—
					0·3	3,687 } 3,623 3,560	

(*) Memorial des poudres, &c., Vol. II., page 8 (1885). Berthelot and Vieille, "Sur les propriétés explosives du fulminate de mercure."

(†) These two numbers, the second of which gives a ratio $\frac{P}{\Delta}$, less than the density 0·2 than to the density 0·1, are inconsistent. The very shattering character of nitromannite has, doubtless, falsified the observations.

Q	Q_k	t	f	a	Δ'	P	$\frac{P}{\Delta}$

III.—MIXTURES OF DYNAMITE AND NITRATE OF AMMONIA (*).

$$2\,C_3H_5N_3O_9 + mN_2H_4O_3 + 151 \text{ grammes silica}$$

$$= 6\,CO_2 + (5 + 2\,m)\,H_2O + \left(0{\cdot}5 + \frac{m}{2}\right) O_2 + (3 + m)\,N_2,$$

$$Q = 671{\cdot}2 + 30{\cdot}4\,m.$$

$$\omega' = 605 + 80\,m,\ \omega = 454 + 80\,m.$$

a. — $m = 29{\cdot}2$, 20 dynamite and 80 nitrate.

$\omega' = 2{,}941$ grammes, $\omega = 2{,}790$ grammes.

1,558·9	530·1	1,500°	6,260	0·934	—	—	—

b. — $m = 7{\cdot}81$, 50·5 dynamite and 49·5 nitrate.

$\omega' = 1{,}229{\cdot}8$ grammes, $\omega = 1{,}078{\cdot}8$ grammes.

908·6	739	2,000°	7,440	0·865	—	—	—

IV.—MIXTURES OF GUN-COTTON WITH NITRATE OF AMMONIA.

A.—*Endecanitric Cotton* (†).

a.—Mixture giving complete combustion of the cotton.

$$M = C_{24}H_{29}N_{11}O_{42} + 20{\cdot}5\,N_2H_4O_3 = 24\,CO_2 + 55{\cdot}5\,H_2O + 26\,N_2,\ \omega = 2{,}783.$$

41 cotton + 59 nitrate.

3,117	1,121	2,420°	8,630	0·847	0·2 0·3	2,092 (‡) 3,488	—

b.—$M + m\,N_2H_4O_3,\ \omega = 2{,}783 + 80\,m.$

$$Q = 3{,}117 + 30{\cdot}4\,m.$$

1st.—$m = 24{\cdot}24$,

24·2 cotton + 75·8 nitrate, $\omega = 4{,}863$ grammes.

3,854	816	2,000°	7,580	0·881	—	—	—

2nd.—$m = 134{\cdot}9$, 8·4 cotton + 91·6 nitrate, $\omega = 13{,}575$ grammes.

7,218	532·0	1,500°	6,370	0·954	—	—	—

B.—Octonitric Cotton and Nitrate of Ammonia.

a.—Mixture giving complete combustion of the cotton.

$$C_{24}H_{32}N_8O_{36} + 28\,N_2H_4O_3.$$

31 cotton + 69 nitrate, $\omega = 3{,}248$ grammes.

3,382	1,041	2,265°	8,460	0·879	—	—	—

(*) See figure 5. (†) See figure 6.

(‡) "Recherches experimentales sur la décomposition du coton-poudre," by Messrs. Sarrau and Vieille.—Study No. 3 (Archives de la commission des Substances Explosives). P has been calculated, starting from crushing, by the formula $K_0 + Ks$, which Messrs. Sarrau and Vieille had not yet established at the time of the publication of that work.

b.—$C_{24}H_{32}N_8O_{36} + 5{\cdot}4\ N_2H_4O_3$.
70 cotton + 30 nitrate, $\omega = 1{,}440$.

Q	Q_k	t	f	α	Δ'	P	$\frac{P}{\Delta}$
1,273·3	884	2,170°	8,620	0·933	—	—	—

c.—$C_{24}H_{32}N_8O_{36} + 50{\cdot}4\ N_2H_4O_3$.
20 cotton + 80 nitrate, $\omega = 5{,}040$.

Q	Q_k	t	f	α	Δ'	P	$\frac{P}{\Delta}$
4,083	810	1,930°	7,610	0·915	—	—	—

V.—OCTONITRIC COTTON AND NITRATE OF BARIUM.
Mixture giving complete combustion of the cotton.
$C_{24}H_{32}N_8O_{36} + 5{\cdot}60\ N_2O_6Ba$, $\omega' = 2{,}469{\cdot}6$, $\omega = 1{,}612{\cdot}8$.
40 5 cotton + 59·5 nitrate.

Q	Q_k	t	f	α	Δ'	P	$\frac{P}{\Delta}$
1,983·4	803	2,648°	7,590	0 686	—	—	—

VI.—BLASTING-GELATINE.
Mixture, with complete combustion of nitro-glycerine and endecanitric cotton.
$C_{24}H_{31}N_9O_{38} + 51\ C_3H_5N_3O_9$, $\omega = 12{,}630$ grammes.

Q	Q_k	t	f	α	Δ'	P	$\frac{P}{\Delta}$
19,511	1,545	3,220°	9,360	0·709	—	—	

The preceding calculations, and some others, which are not reproduced here, being of less interest, are the calculations from which the curves, shewn in figures 5, 6, and 7,* have been traced. These curves shew the manner in which the temperature of detonation, and the explosive force *f*, vary for mixtures, in different proportions, of dynamite or gun-cotton with various substances liable to decomposition under the influence of a high temperature.

COMPARISON BETWEEN THE CALCULATED PRESSURES AND THE PRESSURES EXPERIMENTALLY OBSERVED.

The calculated figures for the temperatures of detonation and the explosive forces *f*, depend on such of the calorimetric indications as can be considered certain; upon the formulæ of the decomposition of explosives which are only certainly known when the explosive is completely burnt; lastly, upon the values of the specific gaseous heats deduced from these experiments. It is very interesting to compare the calculated results with the observations of Messrs. Sarrau and Vieille on the pressures developed by the gases resulting from the decomposition of explosives in closed vessels.

Indeed these pressures may be calculated by the formula

$$P = \frac{f\,\Delta}{1 - \alpha\,\Delta}, \qquad (1.)$$

when *f* is known. But there is then interposed another co-efficient α which is never known with certainty. Furthermore the preceding equation which is no other than that of Clausius, has, up till now, only been verified for comparatively small pressures and for very high temperatures.

(*) See pages 22 and 23.

The attempted verification will, therefore, depend on four elements :—

1st. The accuracy of the law of increase of specific heats which has been assumed, and that of the independence of the specific heat and of the pressure, which has been ascertained by Messrs. Berthelot and Vieille, as well as by ourselves, as far as 16 or 17 atmospheres ;

2nd. The accuracy of the expression (1) which follows directly from the equation of Clausius ;

3rd. The accuracy of the value 0·001 which has been assigned to the co-volume, and which has been assumed to be the same for all gases ;

4th. The correctness of the mode of decomposition of the explosive, adopted in the calculations.

For this verification formula (1) has been transformed into

$$\frac{P}{\Delta} = \alpha P + f. \qquad (2.)$$

The experimental pressures P under the various charging densities Δ being known, calculating $\frac{P}{\Delta}$, and considering the values of P as the abscissæ and the values of $\frac{P}{\Delta}$ as the ordinates of a line ; this line, if the theories are correct, should be a straight line, the angular co-efficient of which $\alpha = \frac{u\, v_0}{\omega}$ depends solely upon the co-volume, and whose originating ordinate f depends upon the temperature of detonation to which it is proportional, and the gaseous volume which itself depends upon the law of decomposition.

The experimental points having for their abscissæ P and for their ordinates $\frac{P}{\Delta}$ should be placed on this theoretical straight line.

If the specific gaseous heats and the law of decomposition assumed in these theoretical calculations are not accurate, but if the law of the co-volume is so, the experimental points should be in a straight line ; lastly, if the value assumed for the co-volume is accurate, which assumes the correctness of the law of decomposition, this straight line must have an inclination defined by the theoretical angular co-efficient α.

On figure 8 (p. 25) the experimental points, for various explosives, deduced from the trials of Messrs. Sarrau and Vieille, have been placed on a plan in which the scale of the abscissæ is the same as that of the ordinates. To understand all the relative values for the various explosives, on the same page, and to avoid confusion, the origin of the ordinates is different with each explosive.

The lines representing the theoretical co-efficient α which pass, as nearly as possible, through the experimental points, are continuous lines.

It is, first of all, evident from an examination of the figure, that the experimental points (if those which have no relation with the others, and are evidently erroneous are eliminated), depart very little on one side or the other from the lines thus traced.

With nitrate of ammonia, for example, the two observations are placed exactly on the line of inclination α. It is the same for the mixture of cotton and nitrate of ammonia giving completely burnt products.

With cotton-powder and picric acid the agreement is also very satisfactory, and especially it is the case with picric acid which has been observed as far as the enormous pressure of 7,660 kilogrammes.

DEDUCTIONS AS TO THE LAW OF THE CO-VOLUME AND THE VALUE OF THAT CO-EFFICIENT.

It results, therefore, from this first point that the formula of the co-volume verified from the lowest pressures up to 10 or 20 atmospheres, is still true for pressures which surpass 7,500 atmospheres. The identity of the co-volume for all gases which has been assumed, and the value of 0·001 attributed to that co-volume, are thus verified in as satisfactory a manner as possible, for the nature of the burnt gases is very different with picric acid, on the one hand, which contains only one volume of water vapour and one volume of carbonic acid against 16 volumes of perfect gases, and with nitrated cotton on the other, which contains 24 volumes of carbonic acid and 55·5 volumes of water vapour, against 26 volumes of perfect gases.

The experiments of Messrs. Sarrau and Vieille would, therefore, tend to shew that, from the lowest pressures up to those of 7,000 or 8,000 atmospheres, the gaseous molecules had an invariable volume, the same for all, and very nearly equal to the one thousandth of the gaseous volume at zero centigrade and 760 millimetres pressure.

DEDUCTIONS AS TO THE VARIATION OF THE SPECIFIC HEATS OF THE CONDENSED GASES WITH TEMPERATURE AND PRESSURE.

On figure 8, by the side of the continuous line, which may be called the experimental line, a dotted line having the same inclination a, and having the value of f found by calculation as the ordinate at origin, has been drawn.

The space between these two straight lines, experimental and theoretical, is represented by the differences of the ordinates at the origin of each of them.

The two straight lines are very little different, one from the other, for nitrate of ammonia ; the difference between the two ordinates at the origin, 5,400 and 5,180 is 220, or a proportional error of about 4 per cent. This difference may be considered as insignificant.

With dynamite there was only one experiment. The theoretical line is above the experimental line by (8,410 — 8,165 =) 245, or a proportional error of 3 per cent., which may also be considered as unimportant.

With cotton and nitrate of ammonia the coincidence of the two lines is almost perfect. The theoretical line is below the experimental line by (8,680 — 8,630 =) 50, a proportional error of 0·57 per cent., which is in the class of accidental errors.

For endecanitric cotton the difference is greater ; the theoretical line is above the experimental line by (9,490 — 8,700 =) 790, or a proportional error of 8·4 per cent.

With picric acid the difference is still greater ; the theoretical line is again above the experimental line to the extent of (9,600 — 8,650 =) 950, or a proportional error of 10 per cent.

It, therefore, follows from this comparison that substances which yield, on decomposition, very little of the perfect gases, such as dynamite (24 per cent. of perfect gases) or ammonia-cotton (24·8 per cent. of perfect gases) shew a very satisfactory agreement between theory and experiment, the difference not surpassing 3 per cent.

It may be concluded that the expressions of the specific heats of carbonic acid and aqueous vapour, deduced from the earlier experiments, ought to be practically accurate ; that these expressions can be extended as far as 3,000 degs. ; and lastly, that they are still independent of the pressure, even when the pressure amounts to 3,000 or 4,000 atmospheres.

DEDUCTIONS AS TO THE EXISTENCE OF THE VARIATION WITH TEMPERATURE OF THE SPECIFIC HEAT OF PERFECT OR NON-CONDENSIBLE GASES.

The theoretical lines for cotton and picric acid depend on the law assumed for the formula of decomposition, and, in a great measure at least, on the law of increase in the specific heat of perfect gases, which has an especial importance, for the reality of the increase itself remains doubtful to many scientists.

For endecanitric cotton, the formula of decomposition assumed appears sufficiently established; it follows from analyses made by Messrs. Sarrau and Vieille, of the gases yielded by detonation. It is true that these gases, during the cooling, may re-act mutually, so that the composition observed may be very different from the composition at the instant of detonation. Nevertheless it can be taken as certain that it is not composed of hydro-carbons in notable proportion. The formula of decomposition should then be, as previously shown, represented by the expression

$$(-1{\cdot}5 + \delta)\,CO_2 + (25{\cdot}5-\delta)\,CO + (14{\cdot}5-\delta)\,H_2O + \delta\,H_2 + 5{\cdot}5\,N_2.$$

The number δ can vary only from $\delta = 0$ to $\delta = 14{\cdot}5$; the amount of heat experimentally ascertained cannot vary. Under these conditions the value of f can only vary from 9,170 to 9,440.

These numbers allow the difference between the theoretical and experimental lines to remain always in the same relation.

The theoretical line has been calculated by assuming a certain increase (a very small one) of the specific heat of simple gases, according to the formula $4{\cdot}8 + 0{\cdot}0006\,t$. If this increase was not assumed, the temperature of detonation would be 2,820 degs. C and $f = 10{,}060$. The experimental f is 8,700; the difference would be 1,360, or the relatively enormous error of 15⅓ per cent.

The increase in the specific heat of perfect gases is, therefore, a certain consequence of the experiments of Messrs. Sarrau and Vieille.

DEDUCTIONS AS TO THE RATE OF INCREASE WITH TEMPERATURE OF THE MOLECULAR SPECIFIC HEAT OF PERFECT OR NON-CONDENSIBLE GASES.

The rate of increase, 0·0006 per degree of the specific heat has been deduced from these experiments, rather discordant on this point, because this value is shewn as the difference between quantities themselves variable. A maximum value of 0·0012 and a minimum value of 0·0003 have been found for this coefficient. The assumed value 0·0006 was an average which is presented with due reservation.

It is natural to seek what would be the value that must be attributed to this increase to bring about a coincidence between the theoretical and experimental lines. The calculation is simple, and with the experimental value of $f = 8{,}700$, t will $= 2{,}437$ and for perfect gases, the expression

$$4{\cdot}8 + 0{\cdot}0014\,t.$$

This rate of increase appears a little too great. It is greater than that which was deduced from the experiments of Messrs. Berthelot and Vieille with cyanogen burning to CO, and which was 0·0011.

The formula of decomposition of picric acid is not well known. Messrs. Sarrau and Vieille, according to the analyses of the gases resulting from detonation, give the following formulæ:—

$\Delta = 0{\cdot}1$. $1{\cdot}37\,CO_2 + 10{\cdot}50\,CO + 0{\cdot}122\,CH_4 + 2{\cdot}00\,H_2 + 0{\cdot}75\,H_2O + 3\,N_2,$

$\Delta = 0{\cdot}2$. $2{\cdot}50\,CO_2 + 8{\cdot}60\,CO + 0{\cdot}870\,CH_4 + 0{\cdot}87\,H_2 + 0{\cdot}37\,H_2O + 3\,N_2,$

$\Delta = 0{\cdot}5$. $3{\cdot}12\,CO_2 + 7{\cdot}62\,CO + 1{\cdot}190\,CH_4 + 0{\cdot}50\,H_2 + 0{\cdot}25\,H_2O + 3\,N_2.$

The salient fact shewn by these analyses, is the presence of marsh gas in notable quantity and increasing with the charging density. This gas has a great influence, as Messrs. Sarrau and Vieille remark, on the amount of heat of decomposition.

741527 A

With the figures given, this amount of heat would be :—

3·12 × 94·0 = 293·3 calories.
7·62 × 25·8 = 196·6 do.
1·19 × 18·5 = 22·0 do.
0·25 × 58·0 = 14·5 do.

526·4 do.
Heat of formation of the acid 98·2 do.

428·2 do.

The temperature of detonation can be calculated with this number. It is true that the rate of increase of the specific heat of marsh gas with temperature is not known, but that only having little influence, the same rate as for CO_2 may be assumed. Thus the analysis of Messrs. Sarrau and Vieille, with a charging density of 0·5 leads to a detonating temperature t = 3,300 degs., to an f = 10,410 and to an $\alpha = 0{\cdot}77$

But a straight line having an inclination, represented by this new value of α, cannot pass at once through all the experimental points, as shewn in figure 8. Further, a straight line passing through the observed point, corresponding to the density 0·3, and having the inclination $\alpha = 0{\cdot}77$ gives an $f = 9{,}420$, which differs considerably from 10,410. The analyses of Messrs. Sarrau and Vieille, therefore, do not agree with their observations of pressure, if they are considered as representing the composition of the gases at the moment of detonation; and it is very probable that the gases analysed had already undergone many transformations during cooling.

However this may be, if the law of decomposition be allowed, which has been assumed in supposing that the decomposition does not give rise to any hydrocarbons, inquiry should be made as has been made with carbonic acid, as to what rate of increase in the heat of the perfect gases will bring about coincidence between the experimental and theoretical lines.

It will be found that for the detonating temperature t = 2,227 degs., and for the specific heat of perfect gases

$$c = 4{\cdot}8 + 0{\cdot}0013\,t.$$

The rate of increase does not differ much from that which has been deduced from the experiments made with gun-cotton.

In any case, the result of this inquiry is the incontestable reality of the increase in the specific heats of the perfect gases with the temperature. As to the rate of this increase, laid down linearly, it would appear to be more marked than that (0·0006), which has been assumed, and even much greater than that (0·0011) resulting from the experiments of Messrs. Berthelot and Vieille.

Unfortunately the uncertainty of the mode of decomposition of gun-cotton and picric acid does not permit the deduction of positively certain conclusions as to the exact value of this co-efficient.

NOTE B.

ON THE QUANTITY OF HEAT WHICH CAN BE TRANSFORMED INTO WORK BY THE ADIABATIC EXPANSION OF A GAS.

By Messrs. Mallard and Le Chatelier.

The solution of the question, now to be considered, is well known in the case where the specific heat of gases is assumed to be constant. In that case, if

T_0, the absolute initial temperature of the gas,
T, the absolute final temperature of the gas,
P_0, the initial pressure,
P, the final pressure,
V_0, the initial volume,
V, the final volume,
Q, the quantity of heat equivalent to the work, effected by the adiabatic expansion from P_0 to P,
c, the specific heat of the gas under constant volume,
c', the specific heat of the gas under constant pressure,

It is known that

$$\frac{V}{V_0} = \left(\frac{P_0}{P}\right)^{\frac{c}{c'}}$$

$$\frac{T_0}{T} = \left(\frac{P_0}{P}\right)^{\frac{c'-c}{c'}};$$

$$Q = c\,(T_0-T).$$

Analogous equations can be easily formed, naturally a little more complex, when the specific heat under constant volume, is a function of the temperature.

Supposing that the temperature remains high enough and $\frac{V_0}{V}$ is relatively large, then the equation of Clausius can be reduced to the expression

$$(1) \qquad P\,(V-u\,v_0) = RT = \frac{10{,}330 \times v_0}{273}\,T,$$

u being the co-volume, and v_0 the volume of the gas at 0°C and 760 millimetres pressure, P being expressed in kilogrammes, V and v_0 in cubic metres.

By differentiation it may be deduced that

$$(2) \qquad d\,V = R\frac{d\,T}{P} - RT\,\frac{d\,P}{P^2};$$

The gases following the law of adiabatic expansion, then, A being the calorific equivalent of a kilogram-metre,

$$(3) \qquad A\,P\,d\,V = -\,C\,d\,T,$$

C being the *true* specific heat of the mass of the gas under consideration.

k

From equations 1 and 2, it follows that

$$(4) \qquad \left(1 + \frac{C}{A\,R}\right) \frac{d\,T}{T} - \frac{d\,P}{P} - 0.$$

If the *average* specific heat, under constant volume, of the mass of the gas, between 0°C and $t°$ is expressed by $c = a + b\,t$, then for the true specific heat, at t

$$C = a + 2\,b\,t = a + 2\,b\,(T - 273),$$

or, by taking

$$a' = a - 2\,b \times 273,$$
$$C = a' + 2\,b\,T.$$

Transposing this value of T into the equation and integrating, it becomes definitely

$$(5) \qquad \left(1 + \frac{a'}{A\,R}\right) \text{log nep. } T + \frac{2\,b}{A\,R}\,T - \text{log nep. } P = \text{constant.}$$

If the specific heat be supposed constant and equal to c, then $b = o$, $a' = c$, and the equation would be reduced to

$$\frac{T_0}{T} = \left(\frac{P_0}{P}\right)^{\frac{A\,R}{A\,R\,+\,c}}.$$

Moreover, if we refer back to the value of R, it will be seen that A R is the quantity of heat, equivalent to the work of the expansion of the gas, under atmospheric pressure for 1 deg. variation in temperature; therefore, $A\,R = c' - c$, which reconciles the expression with the known form

$$\frac{T_0}{T} = \frac{P_0}{P}^{\frac{(c' - c)}{c'}}.$$

By placing in (4) the value of P drawn from (1), it would be easy to get an equation between V and T; which it is useless to set down.

As to the quantity of heat Q expended by the gas in producing expansion from P_0 to P, it corresponds to the loss of internal energy in the gas from T_0 to T, and may be expressed

$$(6) \qquad Q = a\,t_0 + b\,t_0^2 - (a\,t + b\,t^2),$$

calling t_0 and t the temperatures reckoned from zero, which respectively correspond to the absolute temperatures T_0 and T.

The formula (5), when ordinary logarithms are introduced, and the constant is determined by writing, the expression is verified for the pressure and initial temperature P_0 and T_0, takes the form

$$(7) \qquad \text{log. } \frac{P}{P_0} = \left(1 + \frac{a'}{A\,R}\right) \text{log. } T + M\,\frac{2\,b}{A\,R}\,T - k,$$

and

$$k = \left(1 + \frac{a'}{A\,R}\right) \text{log. } T_0 + M\,\frac{2\,b}{A\,R}\,T_0,$$

M being the ordinary logarithm of e.

When the value of $T = t + 273$ has been deduced from equation (7) for any given expansion $\frac{P}{P_0}$, the quantity of heat Q_u utilised by the expansion, by means of the expression

$$Q_u = Q - (a\,t + b\,t^2).$$

The following table is formed in this manner. An expansion of 1-10,000th has been assumed, which will reduce to the atmospheric pressure, the gases assumed originally to have a pressure of 10,000 kilogrammes. The table shews for four explosives, the weight ω of the unit of volume assumed equal to 22·32 litres; the co-efficients a and b of the expression of the specific heat of the unit of volume; the initial temperature t_0 of detonation; the final temperature t after the expansion of 1-10,000th; the heat Q_d expended in expansion per unit of weight; the heat Q_k representing the calorific energy developed by the detonation of 1 kilogramme. The co-efficients f, calculated in Note A are also added.

NATURE OF EXPLOSIVE.	ω	a	b	t_0	t	Q_d	Q_k	f
	grms.							
Picric acid	25·45	4·93	·00092	2,560°	69°	724	737	9,420
Endecanitric cotton	25·97	5·30	·00181	2,636°	304°	945	1,168	9,460
Nitro-glycerine	31·31	5·68	·00281	3,170°	978°	1,128	1,478	9,320
40 endecanitric cotton + 60 nitrate of amonia	26·37	5·50	·00273	2,450°	502°	993	1,121	8,720

An examination of this table shews that a varies little with one explosive or another; while on the contrary b varies greatly; that in proportion as b augments, the final temperature t increases also; and the ratio $\frac{Q_d}{Q_k}$ of the energy Q_d utilized in expansion to the total energy Q_k diminishes.

With explosives whose gases are incompletely burnt, and which consequently consist largely of perfect gases, the expansion utilises almost the whole of the disposable energy.

Besides, this table shews how different is the order in which the explosives can be classed, according to the use to which they are to be applied.

If it is intended to merely produce in a rock, fissures which will allow a subsequent breaking down, it is the pressure developed by the explosive in the shot-hole which is the most important factor, and the value of f will govern the classification.

In mines, the value of f it is evident should be especially taken into consideration.

If, on the contrary, it is desired to excavate and displace a great amount of earth, the value of Q_d becomes the essential element.

The preceding examples shew that, though Q_d may be, especially with explosives completely burnt and with a high temperature of detonation, sufficiently different from Q_k, the difference is not yet great enough so that the total energy Q_k, per kilogramme, can not be taken as the measure of what may be called the *mining* power of the explosive.

It is seen that an explosive can give up, on expansion, almost all the energy which it holds accumulated. The experimental result found by the Sub-Commission, which is equal to about a third part of the total energy of the explosive, the energy transformed into work by detonation in a tin tube of 0·98 inch and 1·57 inches diameter, shews that under these conditions, the share of the disposable calorific energy is far from being all utilized.

In conclusion, it may be remarked that the equation (7) justifies the experimental result obtained by the Sub-Commission, that the temperatures of the gases, after the projection of the sides of any given tube, such, for example, as the tin tube 0·98 inch and 1·57 inches, varies inversely with the density of charging. Indeed, the density of charging diminishes the initial pressure P_0, without changing either the initial temperature T_0 or consequently the co-efficient k. The final pressure P, which, in the experiments of the Sub-Commission, was the atmospheric pressure, also remains the same, the ratio $\frac{P}{P_0}$ increases as the density of charging diminishes; and it follows from equation (7) that the final temperature T also increases.

Issued 28th OCTOBER, 1890.

NORTH OF ENGLAND INSTITUTE

OF

MINING AND MECHANICAL ENGINEERS.

FOUNDED, 1852.—INCORPORATED BY ROYAL CHARTER, 1876.

REPORT OF THE FRENCH COMMISSION ON THE USE OF EXPLOSIVES IN THE PRESENCE OF FIRE-DAMP IN MINES.

PART II.

THIS REPORT, ALTHOUGH ISSUED TO ALL THE MEMBERS OF THE INSTITUTE
BY ORDER OF THE COUNCIL, IS PRINTED PRIMARILY FOR THE
USE OF THE EXPLOSIVES COMMITTEE.

Newcastle-upon-Tyne:
PRINTED FOR THE PUBLISHERS BY ANDREW REID, SONS, & CO., 50, GREY STREET.
1890.

SUBSCRIPTIONS.

The Annual Subscription of a Member is Two Guineas, of an Associate Member Two Guineas, of an Associate One Guinea, and of a Student One Guinea.

These Subscriptions are due and payable on the First Saturday of August in each year, in advance for the ensuing year, or immediately after election.

Forms for the nomination of New Members may be had on application to the Secretary.

On Change of Residence, Members will oblige by giving notice thereof to the Secretary, G. A. Lebour, Neville Hall, Newcastle-upon-Tyne.

TRANSACTIONS.

Volumes I. to XXXVI. of the Transactions (excepting Vols. III., IV., V., VI., and XXI., which are out of print) can be had of the Publisher, price 21s. each.

Vol. XXIII., containing the large Map of the South Wales Coalfield, is published at 26s. Single Copies of the Map 10s. 6d.

DUPLICATES.

Notice is always given to Members in the first circular which is issued when a Part of the Transactions is published, and in the case of non-receipt immediate intimation should be given to the Secretary, as by the Rules of the Institute a duplicate copy can only be obtained by making a written application to the Council; and Parts cannot even then be had if they have been stitched together into volumes.

The following works published by the Institute are now ready:—

Price 21s., or Post Free 22s. 2d., A REPRINT OF

VOL. XVII. OF THE TRANSACTIONS OF THE INSTITUTE,

Containing the Report of the Committee on Haulage of Coal Underground.

In Paper Covers, uniform with the Transactions, 5s.; by Post, 5s. 6d.

A GENERAL INDEX TO VOLS. I. TO XXV.

Of the Transactions of the Institute.

Uniform in size with the Transactions,

A Catalogue of the Books and Maps in the Library

of the North of England Institute of Mining and Mechanical Engineers, 260 pp.
Price—To Members, 5s.; to Non-Members, 10s. By Post, 5d. extra.

Royal 8vo, Price 25s. (by Post 25s. 9d.), Containing 64 Illustrations in Autotype,

ILLUSTRATIONS OF FOSSIL PLANTS.

Being an Autotype reproduction of Selected Drawings of Fossil Plants, prepared under the supervision of the late Dr. Lindley and Mr. W. Hutton, between the Years 1835 and 1840. Edited by Professor G. A. Lebour, M.A., F.G.S.

Uniform in Size with the above, Price 8s., by Post 8s. 3d.,

A Catalogue of the Hutton Collection of Fossil Plants,

Including a Synoptical List of the Chief Carboniferous Species not in the Collection. By Professor G. A. Lebour, M.A., F.G.S.

Royal 8vo, Vol. I., 293 Pages. Vol. II., 332 Pages. Vol. III., 329 Pages. Vol. IV., 334 Pages.

Price—To Members 5s. per Volume, except Volume I., 2s. 6d.; by Post 5s. 6d. To Non-Members, 7s. 6d. per Volume; by Post 8s.

PART I. (**A-B**), PART II. (**C-E**), PART III. (**F-K**), AND PART IV. (**L-R**)

OF AN

Account of the Strata of Northumberland and Durham,

AS PROVED BY BORINGS AND SINKINGS.

This Work, when completed, will comprise the whole of the Borings and Sinkings belonging to the late John Watson, Esq., of Willington, Northumberland, bequeathed by Wm. Watson, Esq., High Bridge, Newcastle-on-Tyne, to the North of England Institute of Mining and Mechanical Engineers. A large number of Borings, &c., furnished by Members of the Institute, are added, forming a complete record of all that has been ascertained by these means of the Geological formation of the two counties of Northumberland and Durham.

☞ *For Officers of the Institute, 1890-91, and Dates of Meeting, see p. 3 of Wrapper.*

REPORT

OF THE

(FRENCH) COMMISSION

ON THE

USE OF EXPLOSIVES

IN THE

PRESENCE OF FIRE-DAMP IN MINES.

PART II.

TRANSLATED BY

W. J. BIRD AND M. WALTON BROWN.

NEWCASTLE-UPON-TYNE:
PRINTED BY ANDREW REID, SONS, & CO., 50, GREY STREET.
1890

SUPPLEMENTARY REPORT
OF THE (FRENCH) COMMISSION
ON THE
USE OF EXPLOSIVES
IN THE
PRESENCE OF FIRE-DAMP IN MINES.

IN the report of the 5th July 1888, the Commission stated that the experiments would be continued in such a way as to solve, as far as possible, certain questions still remaining doubtful. The months of July, August, September, and October, 1888, have been employed in these new researches, the results of which are now published.

I.—EXPLOSIVES IN PRESENCE OF MIXTURES OF AIR AND COAL GAS.

It seemed interesting to experiment with inflammable gaseous mixtures in which marsh gas was replaced by (illuminating) coal gas. Indeed, it was desirable that trials similar to those which had been made at the Sevran-Livry Powder Mill by the Commission should be repeated without too many difficulties, either to ascertain the degree of safety of any new explosive, or to ensure that explosives supplied by manufacturers should give the necessary degree of safety. It was, therefore, very desirable that trials should be made, and that marsh gas, the manufacture of which in quantities is both difficult and costly, should be replaced by coal gas.

The most explosive mixtures of air and coal gas contain from 15 to 16 per cent. of gas. The power of the ejector was insufficient to allow the preparation of similar mixtures in the boiler. Experiments made with mixtures containing 10·3 per cent. of coal gas were considered sufficient for the objects in view. Moreover, it was observed that the inflammability varied little, within certain limits, with the proportions of the mixture.

It was sought, as in the case of mixtures of air and fire-damp, to determine, for mixtures of air and of coal gas, the apparent temperature of ignition under the influence of the detonation of explosives.

Tin tubes of 0·98 inch and 1·57 inches diameter, in which 771·6 grains of various explosives were successively stemmed, were burst in the midst of gaseous mixtures.

Under these conditions, mixtures containing 10 gun-cotton and 90 nitrate of ammonia, 20 cotton and 80 nitrate, and 30 cotton and 70 nitrate were tried. None of these mixtures ignited the gas. It was useless to experiment with mixtures containing larger proportions of gun-cotton, because the mixture of 30 per cent. of cotton gives complete combustion and the highest temperature; on the other hand, by increasing the proportion of cotton, the gases produced by the detonation would have been combustible and might have ignited in contact with the gaseous mixture.

S+B 21 Sept 1934

Afterwards, mixtures of dynamite and nitrate of ammonia were tried. Mixtures containing respectively 60, 70, 80, and 90 of dynamite when detonated in a tin tube 0·98 inch and 1·57 inches diameter, did not ignite the gaseous mixture. Dynamite unmixed with nitrate, on the contrary, produced this ignition, when detonated in the same manner.

The gases resulting from the detonation of a mixture of 90 of dynamite and 10 of nitrate, after having accomplished the necessary work of shattering the tube and projecting its debris, retained, as was shewn in the report of the 5th July, only 63 per cent. of the original amount of heat.

It follows from this, that the temperatures of the gases, when they come in contact with the external gaseous mixture, is about 3,758 degs. F. It has been previously calculated that dynamite, under the same conditions, gives gases of a temperature of 3,902 degs. F.; the apparent temperature of ignition of a mixture of air and coal gas containing 10 per cent. of this gas, would, therefore, be about 3,812 degs. F. With mixtures of air and fire-damp, the temperature was found to be about 3,992 degs. F.

As regards this temperature, thus determined in a roughly approximate manner, it is necessary to make the same reservations as those which have already been made in the first report when treating of marsh gas.

However this may be, it is evident that the inflammability of mixtures of air and coal gas, under the conditions of the experiments, is not much greater than that of mixtures of air and fire-damp. Therefore, without too much exaggeration, the condition of not igniting, at least in the great majority of cases, mixtures of air and coal gas, in which they are detonated unconfined, may be imposed upon the explosives intended for use in fiery mines.

This conclusion, moreover, up to a certain point, might have been expected from the experiment made in May, 1887, in the laboratory of the School of Mines, of which an account was supplied to the Commission. It was ascertained that a plugged detonator containing 23·15 grains of fulminate, and detonating in a bomb of a capacity of 244·11 cubic inches, ignited neither the mixture containing 10 per cent. of fire-damp, nor that containing 15 per cent. of coal gas, although it did ignite the mixture containing 30 per cent. of hydrogen.

II.—INFLUENCE OF AQUEOUS VAPOUR UPON THE INFLAMMABILITY OF FIRE-DAMP MIXTURES.

Certain capricious effects of explosives detonating unconfined had led to the supposition that the inflammability of the gas might vary with certain circumstances, and particularly with the humidity of the air. Experiments undertaken in the laboratory have not confirmed this hypothesis, and no appreciable difference has been found between the inflammability of more or less humid mixtures.

III.—ON THE METHOD OF DETONATION OF EXPLOSIVES.

In the previous report, everything of interest as regards the object of these researches has been shewn concerning the study of a question still imperfectly known, in spite of the valuable studies of Messrs. Berthelot, Sarrau, and Vieille, respecting the mode of the detonation of explosives.

On one side, it is important, with the numerous explosives which have been invented, to be able to ascertain with some precision the greater or less aptitude of their detonation; for a very imperfect aptitude, *a priori*, would be enough to reject the use of the substance.

On the other side, the temperature of the detonation is one of the most important elements affecting safety, and it depends essentially on the mode of decomposition.

Lastly, the mode of decomposition of the same explosive substance varies with the circumstances under which the detonation occurs. It is certainly, at the least, not necessarily the same when the substance detonates unconfined, or when it detonates in a resisting vessel, and the conditions of safety may vary much in one case or the other.

Without hoping to completely solve these delicate questions, till now but little studied, it appeared interesting to multiply researches on this point. A certain number of new facts have been added to those contained in the first report, and for greater clearness the old and the new facts will be here summarized.

The experimental methods which have been employed, and the motives of which have already found a place in the first report, will be again described.

Mode of Conducting the Experiments.

To ascertain the quantity of heat disengaged by the detonation of an explosive, the detonation was made in the closed boiler, and the pressure developed by the rise of internal temperature due to detonation was measured by means of a water-gauge. The temperature falls rather rapidly by cooling; by observing for some seconds the progress of this cooling, the pressure developed at the very moment of detonation, before the cooling had commenced, may, by an allowable assumption, be estimated. The pressure P being known (in metres of water), and the capacity of the boiler (thus transformed into an air calorimeter), then the quantity of heat Q developed in the boiler may be expressed by

$$Q = 58{\cdot}4\ P.$$

Unconfined Detonation.—When the explosive detonates unconfined, Q is the quantity of heat developed by the detonation. Indeed, this is confirmed by the following experiments, made with substances whose mode of unconfined detonation may be considered as well known.

NATURE OF EXPLOSIVE.	Weight of Explosive.	Pressure of Water Column.		Q deduced for 1,543·2grs.	Q theoretical for 1,543·2 grs.
	Grains.	Metres.	Inches.		
Nitromannite	385·8	0·61	24·02	142·0	145·0
Dynamite No. 1 (Vonges)	771·6	0·83	32·68	97·0	97·2 (*)
90 dynamite, 10 nit. of amm.	385·8	0·41	16·14	96·0	91·3
80 do., 20 do.	385·8	0·38	14·96	89·0	85·4
70 do., 30 do.	385·8	0·34	13·39	79·0	79·4
60 do., 40 do.	463·0	0·36	14·17	70·0	73·5

The agreement between the numbers in the two last columns is very satisfactory, if the inevitable uncertainties of the experiments be considered, no attempt being made to secure the precision of which they might be susceptible.

Detonation in Resisting Vessels.—When the explosive was fired, stemmed in a resisting metallic tube, it was shewn, in the first report, that the quantity of heat communicated to the air in the boiler, at the precise moment immediately after

---

(*) For this and the following explosives, the theoretical quantities of heat have been calculated on the assumption that the heat communicated to the inert earth of the dynamite is not immediately restored to the surrounding air.

the detonation, was equal to the heat of detonation, less that transformed into mechanical work represented by the bursting of the tube and the projection of its fragments.

To deduce from the quantity of heat q observed in the air calorimeter, the quantity of heat Q actually developed by the detonation, it would be necessary to know the ratio $\frac{q}{Q}$. This ratio necessarily varies with the nature and dimensions of the tube. It also varies with the nature of the explosive. The following table, however, shews, at least with explosives whose mode of action is not too unlike, that $\frac{q}{Q}$ remains, with the same tube, almost independent of the nature of the explosive. The experiments mentioned in this table have, moreover, been made with substances whose detonation, it may be assumed with certainty, was complete in the metallic tube, so that Q was known with exactitude.

NATURE OF EXPLOSIVE.	Weight of Explosive.	P. Pressure of Water Column.		Q deduced for 1,543·2 grains.	Q theoretical for 1,543·2 grains.	$\frac{q}{Q}$	$\frac{q}{Q}$ Average.
	Grains.	Metres.	Inches.				
1. Tin Tubes of 0·98 inch and 1·22 inches.							
Dynamite	771·6	0·69	27·17	81	97·2	·83	·80
80 dyn., 20 nitrate... ...	771·6	0·59	23·23	69	85·4	·80	
70 do. , 30 do.	771·6	0·53	20·87	62	79·4	·78	
2. Tin Tubes of 0·98 inch and 1·57 inches.							
Dynamite	771·6	0·52	20·47	61	97·2	·63	·67
90 dyn., 10 nitrate... ...	771·6	0·52	20·47	61	91·3	·66	
80 do. , 20 do.	771·6	0·51	20·08	60	85·4	·69	
70 do. , 30 do.	771·6	0·47	18·50	55	79·4	·69	
3. Tin Tubes of 0·98 inch and 1·77 inches.							
Dynamite	771·6	0·48	18·90	56	97·2	·58	·61
70 dyn., 30 nitrate... ...	771·6	0·44	17·32	51·4	79·4	·65	
4. Lead Tubes of 1·18 inches and 1·38 inches.							
Dynamite	771·6	0·56	22·05	65·4	97·2	·67	·67
5. Lead Tubes of 1·26 inches and 1·65 inches.							
Dynamite	771·6	0·46	18·11	53·8	97·2	·55	·55

Experiments of this nature can, however, only be approximate, for it has been shewn that the quantity of heat transformed into work varies with the manner in which the explosive is charged into the tube, and, however great the care with which it is placed therein, it is impossible to be certain that the charging has always been made in the same manner.

However, it will be seen that, at least with the explosives with which the experiments have been made, account can be taken in a sufficiently precise way of the manner in which an explosive detonates in a tube, or, to speak more exactly, of the quantity of heat which it thus develops on detonating, by multiplying the quantity of heat observed q, by the inverse of the ratio $\frac{q}{Q}$ as shewn in the preceding table, and corresponding to the tube employed.

Experimental Researches.

When the explosive wave is propagated through a medium susceptible of its transmission, this propagation is accompanied with certain chemical reactions which constitute what is called the decomposition of the explosive. To examine the mode of this decomposition, it is necessary to distinguish two classes of explosives:

1.—Simple explosives, or those formed of one chemical substance only;

2.—Dual or multiple explosives, formed of an intimate mixture of two or more substances.

Each of these two classes will be examined in succession.

1.—Simple Explosives.

When the simple explosive contains enough oxygen for its complete combustion, it is known that the mode of decomposition, under the influence of the explosive wave, usually corresponds to complete combustion.

The experiments just reported as regards nitromannite and dynamite, shew indeed a perfect agreement between the quantity of heat deduced by this rule and that which has been experimentally observed.

Nitrate of ammonia should, as an explosive, be ranked in this category. But this substance is much less susceptible of detonation than the former, and it should not even be assumed that its detonation has yet been directly ascertained. By using it in a dry and powdered condition, and stemming it in a tin tube of 0·98 inch and 1·77 inches diameter, true detonation of a cartridge of 771·6 grains has been obtained, under the action of a detonator containing 23·15 grains of fulminate. The quantity of heat disengaged was about 27 calories per 1,543·2 grains, although theory requires 38 calories for the mode of decomposition represented by the formula

$$N_2\,H_4\,O_3 = N_2 + 2\,(H_2\,O) + O.$$

The explosive wave, therefore, has not travelled all over the cartridge, or rather another mode of decomposition has been produced. Mr. Berthelot, it is well-known, laid particular stress on the numerous modes of decomposition which can occur with nitrate of ammonia.

When the explosive does not contain enough oxygen for the complete combustion of all its elements, the mode of decomposition which the explosive wave may produce is little known. If the explosive contains carbon, and if the oxygen is insufficient to burn it entirely to the state of carbon monoxide, it may be assumed that the oxygen is altogether used in the formation of carbon monoxide, the rest of the carbon remaining free. This mode of decomposition is expressed by the formula

$$C_p\ H_{2q}\ O_r\ N_{2s} = r\mathrm{CO} + C_{p-r} + H_{2q} + N_{2s}.$$

This mode of decomposition has been observed by Messrs. Berthelot and Vieille for nitrate of diazobenzol, if the secondary products, which may be attributed to reactions subsequent to detonation, are neglected.

When the oxygen is more than sufficient to transform all the carbon into carbon monoxide, the excess of oxygen is divided between the carbon monoxide and the hydrogen, according to a still unknown law. Messrs. Mallard and Le Chatelier have shewn, in the note affixed to the previous report (*), that whatever this law may be, it is somewhat near the truth to assume that, in this case, the quantity of hydrogen remaining free after the decomposition is the mean between the minimum and maximum quantities which it is permitted to assume.

When the gases produced by the decomposition of the explosive are combustible, they may happen to burn in the external air. At the same time this combustion, subsequent to the true detonation, does not occur in all cases. Indeed, the Commission has not proved the combustion, by the external air, of the gases produced by unconfined detonation, of endecanitric cellulose (military gun-cotton), although it has proved this phenomenon for the gases produced by the unconfined detonation of nononitric (mining) and octonitric cellulose.

The Commission, moreover, has proved that a reduction of the temperature of the gases of the detonation can suppress this ulterior combustion. Indeed, if the gases yielded by the detonation of octonitric cotton happen to burn in the air, when they are detonated without a resisting envelope, they no longer burn when the detonation occurs in a tin tube of 0·98 inch and 1·57 inches, or even in a tin tube of 0·98 inch and 1·22 inches diameter. The detonation is even imperfect under these conditions. This is shewn in the following table :—

NATURE OF EXPLOSIVE.	METHOD OF USING THE EXPLOSIVE.	Weight of Cartridge.	Weight of Fulminate.	Pressure of Water Column.		Q deduced for 1,543·2 grs.	Q calculated for 1,543·2 grs.
				Metrs.	Inches.	Calories.	
		Grs.	Grs.				
Octonitric cotton	Exposed	463·0	23·15	0·52	20·47	100	72 (†)
Do. do.	Tin tube 0·98 inch and 1·22 inches	771·6	23·15	0·39	15·35	53	72
Do. do.	Tin tube 0·98 inch and 1·57 inches	771·6	23·15	0·28	11·02	52	72

2.—*Dual Explosives.*

Two principal classes can be distinguished in which

1.—The gases produced by the simultaneous decomposition of two mixed substances are incapable of mutual reaction ;

(*) See page 57.

(†) This number is reduced to 63 if it is assumed, as is not improbable, that the decomposition under the influence of the explosive wave entails the complete combustion of the hydrogen of the octonitric cotton.

2.—The gases produced by the simultaneous decomposition of two substances are capable of mutual reaction.

In each of these classes, unconfined detonation without an envelope, and detonations in a more or less resisting envelope, should be noted.

First Class—The Gases of the Detonation are Incapable of Mutual Reaction.

The Commission examined mixtures of dynamite and nitrate of ammonia, as as well as those of dynamite and ammonia alum.

Mixtures of Dynamite and Nitrate of Ammonia.

1.—Unconfined Detonation—Unconfined detonation in the boiler has been effected with mixtures in which nitrate of ammonia is found in gradually increasing proportions, beginning with 10 per cent. The results are classified in the following table:—

NATURE OF EXPLOSIVE.	Weight of Cartridge.	Pressure of Water Column.		Q deduced for 1,543·2 grs.	Q calculate for 1,543·2 grs.
	Grains.	Metres.	Inches.	Calories.	
10 dynamite, 90 nitrate ...	771·6	0·08	3·15	9·4	44
20 do. 80 do. ...	771·6	0·17	6·69	20	50
20 do. 80 do. ...	771·6	0·24	9·45	28	50
30 do. 70 do. ...	771·6	0·30	11·81	35	56
40 do. 60 do. ...	771·6	0·45	17·72	53	62
50 do. 50 do. ...	771·6	0·53	20·87	61	68
60 do. 40 do. ...	463·0	0·36	14·17	70	73

NOTE.—In all these experiments the detonator contained 23·15 grains of fulminate.

It is seen, by this table, that complete decomposition of the explosive only occurs with mixtures containing more than 50 per cent. of dynamite. With other mixtures, the decomposition increases with, and in a sensibly proportional ratio, to the proportion of dynamite.

In this last case, it does not happen that the decomposition of the explosive approximates notably to the theoretical decomposition, by increasing the charge of fulminate. Indeed, the mixture of 20 per cent. of dynamite with 80 per cent. of nitrate, under the influence of 61·73 grains of fulminate, has given a pressure equal to 9·84 inches of water; scarcely different from the pressure of 9·45 inches of water obtained with 23·15 grains of fulminate.

2.—Detonation in Resisting Vessels.—By detonating a cartridge of 771·6 grains of the mixture of 20 of dynamite and 80 of nitrate in a tin tube of 0·98 inch and 1·22 inches, a pressure of 8·66 inches of water is obtained, which, taking into account the amount of heat converted into work, corresponds to 32 calories. Unconfined, 28 calories were found, which is almost the same.

By detonating a cartridge of 771·6 grains of the same mixture in a tin tube of 0·98 inch and 1·57 inches, 53 calories were obtained, which corresponds almost exactly to the complete decomposition of the dynamite and of the nitrate.

The decomposition which, unconfined and in the tube of 0·98 inch and 1·22 inches, occurs almost in the same manner and remains incomplete, becomes, therefore, complete in the tube of 0·98 inch and 1·57 inches diameter.

Various Mixtures.

The Commission tried, under the same conditions, the detonation of a mixture of 67 of dynamite and 33 of ammonia alum. The quantity of heat required for the de-hydration of the ammonia alum is about 350 calories per kilogramme. Complete detonation of the dynamite, and complete de-hydration of the alum in the mixture in question, would give 53 calories per 1,543·2 grains; the detonation of the dynamite, the alum remaining unaltered, would give 66 calories.

Unconfined detonation has given 52 calories, which would accord with the total de-hydration of the alum. But it is very probable that this is a mere coincidence, and that the unconfined detonation is only incomplete, for in the tin tube of 0·98 inch and 1·57 inches diameter, the detonation has given 71 calories, that is to say, very nearly equal to the amount of heat corresponding to the detonation of the dynamite, without the diminution which should accompany the de-hydration of the alum.

The ammonia alum has, therefore, not had time for de-hydration, at least to any material extent, during the detonation of the dynamite, even when the detonation occurs in a vessel with resisting sides. Doubtless it would be quite otherwise in a vessel completely closed and of invariable capacity.

It may be now mentioned that the Commission arrived at the conclusion that even in tin tubes of 0·98 inch and 1·57 inches diameter, the mixtures of dynamite and sal-ammoniac detonate without causing, to any notable degree, the decomposition of the sal-ammoniac.

Recapitulating, it seems to follow from the preceding facts, that when a mixture of several substances, whose products of decomposition have no mutual reaction, is detonated, the substances which are not explosive, that is to say, whose decomposition absorbs heat, are only decomposed during the propagation of the explosive wave; and that their decomposition only occurs on detonation in a closed vessel.

With mixtures of dynamite and nitrate of ammonia, the decomposition, unconfined or in tin tubes of 0·98 inch and 1·22 inches diameter, is only complete when the proportion of dynamite exceeds 50 per cent. On the other hand, it is complete in tin tubes of 0·98 inch and 1·57 inches diameter, at least when the proportion of dynam equals or exceeds 20 per cent.

Second Class.—The Gases from the Detonation are Capable of Mutual Reaction.

The Commission experimented with a great number of mixtures formed by adding nitrate of ammonia to a combustible substance, or to one decomposing by detonation into combustible products.

Unconfined Detonation.

Mixtures of Octonitric Cotton and Nitrate of Ammonia.—The annexed table gives the results obtained by the unconfined detonation of mixtures, in various proportions, of octonitric cotton and nitrate of ammonia.

It is interesting to compare the amounts of heat directly observed with those which have been calculated on the hypothesis where the two mixed substances are simultaneously decomposed by the explosive wave, and the products of that decomposition, one a supporter of combustion, the others combustible, do not mutually react. Indeed, it is proved that, as long as the cotton is not in excess, that is to say, does not exceed 60 per cent., the maximum amounts of heat, which appear to correspond to the limit of detonation, and which have been observed with a given mixture by causing detonation with very powerful detonators, are equal to the calculated quantities of heat. It appears, therefore, as if the explosive wave provoked the decomposition of the two mixed explosive substances, without the gases resulting from that decomposition having time, before being dispersed in the surrounding air, for mutual reaction.

UNCONFINED DETONATION.

Nature of Explosive.	Weight of Cartridge.	Weight of Fulminate.	Pressure of Water Column.		Q deduced for 1,543·2 grs.	Q calculated for 1,543·2 grs.	Remarks.
			Metres.	Inches.			
	Grns.	Grns.				(*)	
10 octo. cotton, 90 nitrate	771·6	23·15	0·25	9·84	29	41	Substance powdered.
15 do. , 85 do.	385·8	23·15	0·16	6·30	38	43	do. do.
20 do. , 80 do.	771·6	23·15	0·15	5·91	18	44	Substance compressed, probably damp.
20 do. , 80 do.	463·0	23·15	0·13	5·12	25	44	Substance powdered, probably damp.
20 do. , 80 do.	771·6	23·15	0·34	13·39	40	44	Substance powdered, and dry.
20 do. , 90 do.	771·6	23·15	0·38	14·96	44	44	do. do.
20 do. , 80 do.	771·6	23·15	0·38	14·96	44	44	do. do.
20 do. , 80 do.	385·8	61·73	0·21	8·27	49	44	do. do.
25 do. , 75 do.	771·6	46·30 (†)	0·41	16·14	48	47	do. do.
30 do. , 70 do.	385·8	23·15	0·20	7·87	47	48	do. do.
35 do. , 65 do.	463·0	23·15	0·17	6·69	33	50	Substance powdered, probably a little damp.
35 do. , 65 do.	771·6	23·15	0·43	16·93	50	50	Substance compressed, dry.
40 do. , 60 do.	463·0	23·15	0·27	10·63	53	52	do. do.
60 do. , 40 do.	463·0	23·15	0·35	13·78	68	59	do. do.
70 do. , 30 do.	771·6	23·15	0·92	36·22	107	62	Substance powdered.
80 do. , 20 do.	463·0	23·15	0·63	24·80	123	66	Substance compressed.
90 do. , 10 do.	463·0	23·15	0·94	37·01	183	69	do. do.
100 do. , 0 do.	463·0	23·15	0·59	23·23	115	73	Substance powdered.

When the proportion of octonitric cotton exceeds 60 per cent., the gases produced by the decomposition of this cotton are burnt more or less completely in contact with air, and the quantity of heat observed is then greater than that which would result even from the mutual and complete reaction of the oxygen of the nitrate on the gaseous products of the decomposition of the cotton.

(*) The quantities of heat in this column are calculated on the hypothesis of the decomposition of two mixed substances, without ulterior reaction.

(†) Two detonators of 23·15 grains each.

Mixtures of Dinitro-benzol and Nitrate of Ammonia.—These mixtures are formed by mixing the dry and powdered nitrate with the melted dinitro-benzol. They have given, detonated unconfined, the following results:—

NATURE OF EXPLOSIVE.	Weight of Cartridge.	Weight of Fulminate.	Pressure of Water Column.		Q deduced for 1,543·2 grains.	Q calculated for 1,543·2 grs.
			Metres.	Inches.		
	Grs.	Grs.				
17·5 dinitro, 82·5 nitr. (Bellite)	771·6	23·15	0·25	9·84	29	41
Do.	771·6	23·15	0·28	11·02	33	41
Do.	771·6	46·30 (*)	0·34	13·39	40	41
10 dinitro, 90 nitr	385·8	23·15	0·16	6·30	37	39

NOTE.—Substances powdered.

It seems as if the limit of detonation corresponded to simultaneous decomposition, but without any ulterior mutual reaction of the products of that decomposition.

Mixtures of Picrate and Nitrate of Ammonia.—The following experiments have been made on dry and powdered mixtures of picrate and nitrate of ammonia, filled by hand into paper cylinders:—

NATURE OF EXPLOSIVE.	Weight of Cartridge.	Weight of Fulminate.	Pressure of Water Column.		Q deduced for 1,543·2 grs.	Q′ calculated do. (†)	Q″ calculated do. (‡)
			Metres.	Inches.			
	Grs.	Grs.					
Picrate (alone)	771·6	23·15	0·00	0·00	0	56	0
60 picrate, 40 nitrate ...	771·6	23·15	0·14	5·51	16	49	15
50 do. 50 do. ...	771·6	23·15	0·15	5·91	18	47	19
40 do. 60 do. ...	771·6	23·15	0·19	7·48	22	45	23
28 do. 72 do. ...	771·6	23·15	0·17	6·69	20	43	27
20 do. 80 do. ...	771·6	23·15	0·23	9·05	27	42	30
10 do. 90 do. ...	771·6	23·15	0·00	0·00	0	40	34

This table shews the singular fact that the quantity of heat disengaged by the explosion increases somewhat regularly with the proportion of nitrate, and that it appears as if the explosive wave produced the decomposition of the nitrate alone without producing that of the picrate.

Various Mixtures.—Cartridges have been detonated unconfined, filled with mixtures of nitrate of ammonia with various combustible substances, but not

---

(*) Two detonators of 23·15 grains each.

(†) Assuming the simultaneous decomposition of the two substances, but without ulterior reaction.

(‡) Assuming the decomposition of the nitrate alone.

detonating unconfined by the action of detonators, such as naphthaline, resin, coal-tar, and heavy tar oils. The unconfined detonation of these mixtures is very imperfect, and only gives very small pressures, which indicates, at least in the great number of cases, that the explosive wave dies away before having penetrated through the mass of the explosive.

Summary.—Briefly, the mixtures formed by the addition of various combustible substances (explosive or non-explosive) to nitrate of ammonia, always detonate unconfined in a very imperfect manner. Sometimes the explosive wave, originated at one point, dies away before having penetrated the mass of the explosive; sometimes it appears as if the explosive wave, penetrating through the cartridge, limited its effect to provoking the decomposition of the explosive substances which the mixture contains, the gases resulting from that decomposition being dispersed before any mutual reaction takes place.

Detonation in a Massive and Resisting Vessel.

The effects of detonation in a resisting vessel were next examined.

Detonation was made in a tin tube of 0·98 inch and 1·22 inches diameter, with the following results:—

DETONATION IN A TIN TUBE OF 0·98 INCH AND 1·22 INCHES DIAMETER.

NATURE OF EXPLOSIVE.	Weight of Cartridge.	Weight of Fulminate.	Pressure of Water Column.		Q deduced for 1,543·2 grs.	Q calculated for 1,543·2 grs. (*)	REMARKS.
			Metres.	Inches.			
	Grs.	Grs.			Cal.	Cal.	
20 octonit., 80 nitrate	771·6	23·15	0·34	13·39	50	44	Substance powdered.
90 octonit., 10 nitrate	463·0	23·15	0·27	10·63	66	69(†)	do.
10 dinitro-benz., 90 nitrate ...	771·6	23·15	0·30	11·81	44	39	do.
6 naphthaline, 94 do. ...	771·6	23·15	0·26	10·24	38	...	do.
10 naphthaline, 90 do. ...	771·6	23·15	0·28	11·02	41	...	do.
10 picrate of am., 90 do. ...	771·6	23·15	0·22	8·66	32	39	do.
20 do., 80 do. ...	771·6	23·15	0·30	11·81	40	41	do.
28 do., 72 do. ...	771·6	23·15	0·35	13·78	51	43	do.
40 do., 60 do. ...	771·6	23·15	0·35	13·78	51	45	...
50 do., 50 do. ...	771·6	23·15	0·34	13·39	50	47	...
60 do., 40 do. ...	771·6	23·15	0·30	11·81	40	49	...
100 do., 0 do. ...	771·6	23·15	0·13	5·12	19	56	...
8 coal tar, 92 do. ...	771·6	23·15	0·27	10·63	39	...	Heated 1 hour to 149° F.
12 do., 88 do. ...	771·6	23·15	0·09	3·54	13	...	Not heated.
10 heavy oil, 90 do. ...	771·6	23·15	0·20	7·87	29	...	...

With mixtures of octonitric cotton and dinitro-benzol, detonation is effected in a tin tube of 0·98 inch and 1·22 inches diameter, almost in the same manner as when unconfined; mutual reaction of the products of detonation

---

(*) The quantities of heat are calculated on the hypothesis of the simultaneous decomposition of two substances without ulterior reaction.

(†) 61 calories, when the complete oxidation of the hydrogen of the octonitric cotton is a does not appear to be produced, doubtless on account of the insufficient resistance opposed to the expansion of the gases. It will be remarked that the gases resulting from decomposition of the mixture of 90 cotton and of 10 nitrate, are not ignited on contact with air, as was the case after detonation without covering.

Mixtures of naphthalene and nitrate, which do not detonate unconfined, detonate by disengaging an amount of heat which may be considered as equal to that which the decomposition of the nitrate alone would disengage.

The amount of heat disengaged by the mixture of 8 coal-tar and of 92 nitrate, is very little more than would be given off from the decomposition of the nitrate alone, and which is equal to 35 calories.

The amount of heat given off by the mixture of 10 heavy oil and of 90 nitrate, is a little less than that (36 calories) which the decomposition of the nitrate alone would disengage.

With mixtures of picrate and nitrate of ammonia, the quantities of heat disengaged are generally slightly greater than those resulting from simultaneous decomposition without mutual reaction. Most of the tubes were completely shattered, and there remained in the boiler only the end containing the stemming placed above the explosive. The ends of the tubes containing the mixtures of 10 and 90, and of 60 and 40 were, however, from ·4 to ·8 inches longer than the stemming, shewing that the bottom of the cartridge had not detonated. With these mixtures the amounts of heat observed were less than the amount which would result from simultaneous decomposition without mutual reaction.

The results obtained by detonation in the tin tube of 0·98 inch and 1·57 inches diameter, are very different from the preceding, as the annexed table shews:—

Mixtures of octonitric cotton and dinitro-benzol, on detonation in tubes of 0·98 inch and 1·57 inches diameter, yield amounts of heat corresponding to complete detonation.

With mixtures of mononitronaphthalene, naphthalene, or picrate, the amounts of heat are usually much greater than those which correspond to the decomposition of the nitrate of ammonia, or to the simultaneous decomposition of the two substances, but they are more or less inferior to those which would result from complete detonation.

With mixtures of picrate, except with those which contain 10, 20, or 60 of picrate, it is certain that the metallic tubes were completely shattered in all the parts containing the explosive, which appears to indicate that all the cartridge has detonated, although the amounts of heat observed are very much less than those which should have been developed if the mutual reactions of the gases produced had occurred in their entirety.

With mixtures of coal-tar and of heavy oils, the amounts of heat disengaged are scarcely above those which would result from the decomposition of the nitrate alone.

Lastly, experiments were made in tin tubes of 0·98 inch and 1·77 inches; the results were not very different from those obtained with tubes of 0·98 inch and 1·57 inches diameter.

STUDY OF EXPLOSIVES AFFORDING GUARANTEES OF SAFETY.

The Commission, in its previous report, laid down the principles which ought to guide the search for explosives calculated to secure the safety of fiery mines. The experiments made since the publication of that report have confirmed these principles, and allowed of their extension on certain points.

DETONATION IN TIN TUBES OF 0·98 INCH AND 1·57 INCHES DIAMETER.

NATURE OF EXPLOSIVE.	Weight of Cartridge.	Weight of Fulminate.	Pressure of Water Column.		Q deduced for 1,543·2 grs.	Q calculated for 1,543·2 grs.	REMARKS.
			Metres.	Inches.			
	Grs.	Grs.				(*)	
10 octo. cotton, 90 nitrate ...	771·6	23·15	0·27	10·63	49	59	Powdered, probably a little damp.
15 do. , 85 do. ...	385·8	23·15	0·20	7·87	72	70	Powdered, very dry.
20 do. , 80 do. ...	385·8	23·15	0·21	8·27	84	80	do.
30 do. , 70 do. ...	771·6	23·15	0·42	16·54	75	88	do.
60 do. , 40 do. ...	463·0	23·15	0·30	11·81	90	96	do.
80 do. , 20 do. ...	463·0	23·15	0·28	11·02	84	82	do.
90 do. , 10 do. ...	463·0	23·15	0·23	9·05	69	76	do.
17 dini.-ben., 83 nit. (Bellite) ...	771·6	23·15	0·51	20·08	95	100	do.
10 do. , 90 do. ...	385·8	23·15	0·18	7·09	65	74	do.
9 mononitronaph., 91 nit. ...	771·6	23·15	0·42	16·54	75	97	do.
6 naphthalene, 94 nitrate ...	771·6	23·15	0·38	14·96	68	94	do.
10 do. , 90 do. ...	771·6	23·15	0·29	11·42	52	92	do.
10 picrate, 90 nitrate	771·6	23·15	0·22	8·66	40	60	do.
20 do. , 80 do.	771·6	23·15	0·31	12·20	56	83	do.
28 do. , 72 do.	771·6	23·15	0·31	12·20	56	100	do.
40 do. , 60 do.	771·6	23·15	0·36	14·17	65	94	do.
50 do. , 50 do.	771·6	23·15	0·30	11·81	54	90	do.
60 do. , 40 do.	771·6	23·15	0·27	10·63	48	85	do.
100 do. , 0 do.	771·6	23·15	0·16	6·30	28	...	...
8 coal tar, 92 do.	771·6	23·15	0·23	9·05	41	...	Heated 1 hour to 149° F.
12 do. , 88 do.	771·6	23·15	0·12	4·72	22	...	Not heated.
10 heavy oil, 90 do.	771·6	23·15	0 21	8·27	38	...	...

The Commission ascertained that explosives detonating in metallic tubes, only cease to ignite the most explosive fire-damp mixtures when the work imposed on the gases resulting from detonation is sufficient to reduce their theoretical temperature below 3,992 degs. F.

Hence it is concluded that explosives for use in fiery mines should be sought for among those whose temperature of detonation is less than this figure, and whose gases are not combustible after decomposition. Among the simple explosives, nitrate of ammonia is the only one now known which satisfies this double condition; but this substance, as has been seen above, detonates only imperfectly when it is alone, and its explosive force is inconsiderable. Therefore, it is necessary to resort to dual explosives.

From the composition of the dual mixtures capable of employment, the Commission has discarded the use of substances, which, non-explosive in themselves, are not combustible. Indeed, these substances, as has been previously mentioned, do not

---

(*) The amounts of heat are calculated on the hypothesis that after the decomposition of the two substances, the gases react completely one on the others.

decompose under the influence of the explosive wave. When detonated unconfined, they act, therefore, only by cooling the gases by reason of their capacity for heat, and this necessitates their employment in great excess. But on detonation in a closed vessel, the decomposition as soon as it starts absorbs a great amount of heat, and diminishes the explosive force too much.

Dual mixtures of two classes are, therefore, necessarily used. Either the two mixed substances are both explosive and supporters of combustion; or else one of the substances being explosive and a supporter of combustion, the other, explosive or non-explosive, is capable of being burnt by the excess of oxygen, yielded by the decomposition of the first.

Mixtures of two Combustion-Supporting Substances.

Mixtures of Dynamite and Nitrate of Ammonia.—The only explosives now known which decompose with excess of oxygen are nitro-glycerine, nitromannite, and nitrate of ammonia. The temperature of detonation of nitro-glycerine is about 5,702 degs. F; that of nitromannite is almost the same. It is, therefore, impossible to use these explosives alone, or mixed together. Moreover, nitromannite is a substance whose price is rather high. Thus the only mixtures which can be tried are those of nitro-glycerine and nitrate of ammonia. For these trials the Commission has always used nitro-glycerine in the state of dynamite, that is to say, mixed with 25 per cent. of absorbent silica.

In its manufacture on a large scale, endeavours should be made to dispense with the silica, and to use the nitrate of ammonia as the absorbent body, without risk of finding, under the influence of the atmospheric moisture, the water expelling the nitro-glycerine from the nitrate, thus causing the latter to exude, and making the explosive dangerous to handle.

It was shewn in the previous report that the mixture of dynamite and of nitrate of ammonia, whose temperature of detonation is about 3,992 degs. F., contains 60 parts of dynamite and 40 parts of nitrate. This mixture and all those containing a greater proportion of nitrate, may be, therefore, considered as possessing a certain degree of safety in presence of fire-damp *under ordinary usage*, that is to say, when they explode stemmed (even lightly) in shot-holes. Indeed, a cartridge of 772 grains, containing 60 parts of dynamite and 40 parts of nitrate, has been exploded unconfined in a mixture of air and fire-damp without producing ignition of the explosive mixture. This fact is a strong confirmation of the theories enunciated by the Commission, that this mixture detonates completely when unconfined, as has been shewn above, and that the cartridge has certainly developed, in the midst of gas, the temperature of 3,992 degs. F., or a temperature very near it.

Safety in the use of explosives stemmed in the bottom of a shot-hole is evidently of the greatest importance, for it must be laid down, as an absolutely imperative rule, that explosives shall never be used otherwise, and that in no case and under no pretext should they ever be exploded without covering when unconfined. However, it may be feared that this rule, which should be so imperative, may happen to be broken, either by a clumsy fault of a workman, or by an accident, no doubt rather difficult to imagine, but which is by no means impossible in fact, and which it is proper to provide for.

The experiments of the Commission, agreeing with the Prussian experiments, have shewn that the detonation of explosives without covering gives rise to phenomena which are not always identically reproduced. If substances whose temperature of detonation when unconfined is above 3,992 degs. F., such as dynamite or mixtures of dynamite and of nitrate of ammonia containing more than 60 parts of dynamite, always ignite the fire-damp mixtures, in the midst of which they detonate without covering; mixtures whose temperatures of detonation are below 3,992 degs. F. may, detonating under the same conditions, from causes ill-defined, and which even appear difficult to prevent, produce ignition of the gas. Furthermore, the Commission had taken great care to point out "the complexity and the lack of certainty of the phenomena which may attend the detonation of unconfined explosives." (*)

It has been shewn that, as regards mixtures of dynamite and of nitrate, the unconfined detonation is always produced under well defined conditions, as far as the quantity of heat developed. There are irregularities only in the phenomena of the ignition of the external fire-damp mixture. It seems, therefore, possible, if not very probable, that these irregularities are due to the imperfection, almost impossible to avoid absolutely, of the mixture of the two substances. It is imagined that a portion of dynamite may detonate alone on the surface of the cartridge and cause ignition of the gas. If this is the case, there would be more chances of ignition the greater the surface of the cartridge, that is to say, the bigger the cartridge. There would also be more chances of avoiding ignition when the amount of nitrate was in a higher proportion than that of the dynamite. These two consequences are in agreement with the facts.

To determine the proportions of the mixture of dynamite and nitrate which was suitable for the use of workers of mines, the Commission detonated, unconfined, mixtures in which the proportion of nitrate was gradually increased, and which each time was placed under more dangerous conditions by increasing the weight of the cartridge. The following results have thus been obtained :—

Nature of Explosive.	Cartridges Weighing		
	771·6 grains.	1,543·2 grains.	3,086·5 grains.
60 dynamite, 40 nitrate ...	1 expt. N (†)	...	...
50 ,, , 50 ,, ...	2 expts. N	1 expt. I	...
40 ,, , 60 ,, ...	2 expts. N	1 expt. I	...
30 ,, , 70 ,, ...	1 expt. N	2 expts. N	2 expts. N
20 ,, , 80 ,, ...	1 expt. N	5 expts. N	2 expts. N

Moreover, it was found that a cartridge of 771·6 grains of the mixture of 20 of dynamite and 80 of nitrate could be detonated in a mixture of air and coal gas without igniting it.

The mixture of 20 of dynamite with 80 of nitrate, and even the mixture of 30 of dynamite with 70 of nitrate, may, therefore, be considered as possessing very high guarantees of safety.

(*) See page 43.

(†) N signifies non-ignition, and I ignition of the gaseous mixture.

Moreover, these two mixtures constitute powerful explosives, as is shewn by the following table :—

NATURE OF EXPLOSIVE.	*f* (*)	Q*k* (†)
Dynamite	8,490	1,109
30 dynamite, 70 nitrate	6,750	600
20 do. , 80 do.	6,260	530

The pressure obtained in a closed vessel, by the mixture of 20 of dynamite and 80 of nitrate, with equal density of charging, would be, therefore, almost 0·74 of that which is obtained with dynamite. It is true that the power of projection would be about one-half, but this is an element which plays the least important rôle in mines.

The Commission has ascertained that these explosives detonate completely under the action of plugged caps containing only 7·72 grains of fulminate.

Mixtures of a Combustion-Supporting Substance and a Combustible Substance.

Mixtures in which one of the explosives is a supporter of combustion, and the other a combustible will now be discussed. The excess of free oxygen in the products from the combustion-supporting explosive, being always small, there is an inducement, when it is desired to achieve a complete combustion, which is one necessary guarantee of security, to employ a considerable proportion of that explosive. With dynamite and nitromannite inadmissable temperatures of detonation would be incurred. The only combustion-supporting explosive which can be employed is nitrate of ammonia.

As regards the combustible explosive, on the contrary, the choice is very great ; resort may be had to cellulose more or less nitrated, to dinitro-benzol, to mononitronaphthalene, to nitrate of diazobenzol ; and to various solid or liquid hydrocarbons, &c.

Mixtures of Gun-cotton and Nitrate of Ammonia.—After various trials the Commission selected octonitric cotton, yielding about 173 cubic centimetres of dioxide of nitrogen per gramme (·68 cubic inches, per grain). An explosive is thus obtained at a lower price than if a higher nitric cotton had been used, and it moreover reduces the temperature of detonation.

It was thought desirable to use these mixtures in a compressed state, for their better protection against moisture ; but special experiments have shewn that as soon as the compression reached 25 atmospheres, the explosive detonated badly under the action of one 23 grain detonator. It was then considered sufficient to force the substance by hand into paper cylinders coated with paraffin. A second covering, also of paper coated with paraffin, completed the protection of the substance against moisture.

The complete combustion of octonitric cotton is obtained with a mixture of 30 of cotton and 70 of nitrate. It is, therefore, only this mixture or mixtures with larger proportions of nitrate that should be examined, because the

---

*) *f* is the co-efficient called the force of the explosive in the first report.

†) Q*k* is the amount of heat disengaged by the detonation of 1 kilogramme of the substance.

condition ought to be imposed that, on detonation in a closed vessel, or after stemming at the bottom of a shot-hole, the gases from the detonation shall not be combustible, that is to say, should contain neither hydrogen nor carbon monoxide.

Mixtures more or less rich in nitrate (of ammonia) have been submitted to various trials in the same way as mixtures of dynamite and nitrate. The results have been as follows :—

NATURE OF EXPLOSIVE.	WEIGHT OF CARTRIDGE.		
	771·6 grains.	1,543·2 grains.	3,086·5 grains.
30 cotton, 70 nitrate	...	1 expt. N	...
20 do. , 80 do.	2 expts. N	4 expts. N 1 expt. I	2 expts. I
15 do. , 85 do.	...	...	2 expts. N

The mixture of 20 of cotton with 80 of nitrate affords a sufficient degree of safety, but the safety of the mixture of 15 of cotton and 85 of nitrate is still higher; it is proper, therefore, to recommend this mixture or mixtures still more highly charged with nitrate.

The explosive is sufficiently energetic, as shewn by the following :—

NATURE OF EXPLOSIVE.	f	Qk
Dynamite	8,490	1,109
20 cotton, 80 nitrate	7,610	810
15 do. , 85 do.	7,000	700

With equal density of charging the pressures would be, for the mixture of 15 of cotton and 85 of nitrate, ·83 of the pressures given by dynamite. The amounts of disposable heat are in the proportion of ·64 to 1.

It is well known that these mixtures detonate badly when the weight of fulminate in the detonator is less than 23 grains.

Mixtures of Dinitro-Benzol and Nitrate of Ammonia.—These mixtures are made by melting the dinitro-benzol and incorporating in it very finely powdered nitrate of ammonia. The grains of nitrate are thus in a manner enclosed by the dinitro-benzol; consequently these mixtures are less sensitive to the influence of atmospheric moisture than mixtures of cotton and nitrate. Besides, they are further protected by a double covering of paraffined paper.

Complete combustion is obtained with a mixture of 12·5 of dinitro-benzol, and 87·5 of nitrate. The mixture invented by Mr. Lamm, under the name of Bellite, appears to consist of 15 of dinitro-benzol and 85 of nitrate. The possible proportions of the mixture are very limited. Proceeding in the same manner as with the other mixtures, the following results have been obtained :—

NATURE OF EXPLOSIVE.	WEIGHT OF CARTRIDGE.			
	617·3 grs.	771·6 grs.	1,543·2 grs.	3,086·5 grs.
20 dinitro-benzol, 80 nitrate... ...	...	...	1 expt. N.	...
Bellite	1 expt. N.	1 expt. N.	1 expt. N. 1 expt. I.	...
10 dinitro-benzol, 90 nitrate... ...	1 expt. N.	..	1 expt. N.	2 expt. N. 1 expt. I.

It is seen that the mixture of 10 of dinitro-benzol, and 90 of nitrate, possesses a high degree of safety, because ignition of the gases has only been effected with a cartridge of 3,086·5 grains, and then once only out of two trials. It might be attempted to diminish still further the proportion of dinitro-benzol, and the trial would probably succeed, for the mixture of 10 of dinitro-benzol still detonates very well under the action of a 23 grain detonator. It will be better perhaps to compress, if possible, the substance which has been used in the powdered state in the preceding experiments.

This mixture is, moreover, sufficiently energetic, as is seen by the following table:—

NATURE OF EXPLOSIVE.	*f*.	Q*k*.
Dynamite	8,490	1,109
12·5 dinitro-benzol, 87·5 nitrate...	8,000	1,006
10 do. , 90 do.	6,700	750

The mixture of 10 of dinitro-benzol detonates badly with detonators containing less than 23 grains of fulminate.

Mixtures of Mononitronaphthalene and Nitrate of Ammonia.—Complete combustion takes place with a mixture of 9·15 of mononitronaphthalene and 90·85 of nitrate. In a powdered state this mixture detonates in an uncertain manner when unconfined. It has, in this state, given the following results on detonation, unconfined in the midst of fire-damp:—

CARTRIDGES WEIGHING		
617·3 grains.	771·6 grains.	1,543·2 grains.
1 expt. I.	3 expts. N.	2 expts. N. { Detonation very incomplete.

Mixtures of Naphthalene and Nitrate of Ammonia.—Mixtures of naphthalene with nitrate of ammonia have been tried.

The mixture affording complete combustion contained 6 of naphthalene and 94 of nitrate. It was prepared by pouring the dry and powdered nitrate into the melted naphthalene. This appeared to absorb the nitrate with greater difficulty than was the case with dinitro-benzol. Hence a less perfect enclosing and a more uncertain protection of the nitrate against moisture. The mixture detonates unconfined only in a very imperfect fashion. In the tin tube of 0·98 inch and 1·22 inches the explosive wave produces decomposition, but the detonation, still very incomplete, appears to correspond only to the detonation of the nitrate (see table p. 85). In the tin tube of 0·98 inch and 1·57 inches the detonation is still imperfect, but it approximates to completion, for a production is observed of 68 calories per 1,543·2 grains, although theory exacts 94 calories (see p. 87). It may be assumed, therefore, that in shot-holes properly stemmed the detonation will be complete.

In a shot-hole 40 inches deep, drilled at Sevran in an argillaceous earth, a cartridge of 3,086·5 grains, carefully stemmed, produced a chamber of compression, the three principal dimensions of which were 1 foot 7·7 inches × 1 foot 7·3 inches × 1 foot 5·7 inches.

Experiments made with mixtures of air and fire-damp have given the following results :—

Cartridges Weighing					
1,543·2 grains.			3,086·5 grains.		
Pressure of Water. Column.		Result.	Pressure of Water Column.		Result.
Metres.	Inches.		Metres.	Inches.	
0·04	1·57	N	0·07	2·76	N
			0·10	3·94	N

One of the two 3,086·5 grains cartridges tested was fired by the action of three plugged detonators of 23 grains each, in spite of that the detonation was extremely feeble.

Two cartridges, one of 1,157·4 grains and the other of 1,697·6 grains, stemmed in tin tubes of 0·98 inch and 1·22 inches, have detonated freely without igniting the fire-damp.

Trials have also been made in mixtures of air and coal gas; which have given the following results :—

Cartridges Weighing					
1,543·2 grains.			3,086·5 grains.		
Pressure of Water Column.		Result.	Pressure of Water Column.		Result.
Metres.	Inches.		Metres.	Inches.	
0·03	1·18	N	...	...	I
0·03	1·18	N			

A cartridge weighing 771·6 grains stemmed in a tin tube of 0·98 inch and 1·22 inches detonated freely without igniting the gaseous mixture.

To sum up, therefore, ignition of the internal gas can only be produced by the naphthalene and nitrate mixture, with a cartridge of 3,086·5 grains detonating unconfined in a mixture of air and coal gas.

The naphthalene and nitrate mixture could, therefore, be used advantageously and safely if, as is very likely, its aptitude of detonation was considered practically satisfactory.

The physical and chemical data for this mixture are :—

Naphthalene and nitrate of ammonia.

$$C_{10}H_8 + 24\,N_2H_4O_3 = 10\,CO_2 + 52\,H_2O + 24\,N_2.$$

$$\varpi = 2{,}048.$$

Q.	Qk.	t.	f.	a.
1,930	943	2,070° C.	8,330	0·936

Trials made in a bomb by Mr. Bruneau with 15·43 grains of fine powder as an igniter, have given the following results :—

$\Delta = 0{\cdot}2$, P = 1,850 k, P (theoretical) = 2,050,
$\Delta = 0{\cdot}3$, P = 3,246 k, P (theoretical) = 3,400.

Mixtures of Coal-Tar and Nitrate of Ammonia.—A mixture of 88 of nitrate of ammonia with 12 of coal-tar (in its ordinary state) was also tried.

The substance detonated badly even in tin tubes.

In fire-damp with cartridges of 3,086·5 grains, ignition has only been produced once in three experiments.

In the two experiments where ignition did not occur, the pressure which the detonation produced amounted once to 0·50 metre (19·68 inches), and another time to 0·56 metre (22·05 inches) of water column.

The mixture was heated at 149 degs. F. in a stove for two hours to expel the most volatile matters; two cartridges of 3,086·5 grains thus treated detonated in fire-damp without igniting it, but without producing any notable pressure in the boiler.

A mixture of 8 of tar and 92 of nitrate heated for one hour at 149 degs. F. was also tried. The results of detonation have been, under the same conditions, better than with the preceding mixture.

In fire-damp, two experiments, made with cartridges of 3,086·5 grains, have given in the boiler pressures of 0·58 metre (22·83 inches) and 0·60 metre (23·62 inches) of water column, without igniting the gas; a third experiment ignited it.

Mixtures of Heavy Oils from Coal Tar with Nitrate of Ammonia.—A mixture of 10 of heavy oil with 90 of nitrate of ammonia was tried.

Like the mixture of 8 of tar and 92 of nitrate dried for one hour at 149 degs. F., decomposition even in the tin tube of ·98 inch and 1·57 inches appeared to correspond only to the decomposition of the nitrate of ammonia.

In fire-damp two cartridges of 3,086·5 grains were detonated, producing insignificant pressures, and without igniting the gas.

Mixtures of Resin with Nitrate of Ammonia.—A mixture of 10 of resin and 90 of nitrate of ammonia detonated badly when unconfined, but appeared to detonate well enough in metallic tubes. In fire-damp it has given the following results:—

Cartridges Weighing	
771·6 Grains.	3,086·5 Grains.
1 expt. N.	2 expts. N.

Mixtures of Picrate of Ammonia with Nitrate of Ammonia.—Picrate of ammonia ($C_6 H_6 N_4 O_7 = 246$) may be supposed to decompose according to the formula $6 CO + H_2O + 2 H_2 + 2 N_2$, it will then disengage 137 calories (water gaseous) at constant volume per 246 grammes or 3,796·4 grains, or 560 calories per kilogramme.

Its aptitude of detonation is medium, for it has not been detonated unconfined, and it only detonated very incompletely in tin tubes of ·98 inch and 1·57 inches.

Complete combustion requires the mixture of 27·7 of picrate with 72·3 of nitrate of ammonia. This mixture only detonated very incompletely when unconfined (see page 84, for table).

Two mixtures, one containing 10 of picrate and 90 of nitrate, the other containing 20 of picrate and 80 of nitrate, were tried in mixtures of air and fire-damp. The results were as follows:—

Nature of Explosive.	Cartridges weighing 3,086·5 grains.	Remarks.
10 picrate, 90 nitrate ...	2 expts. N. ...	Detonation very incomplete.
20 do. , 80 do. ...	1 expt. I. ...	

Moreover, these mixtures have very little practical interest, as they are relatively somewhat costly, and they would have no advantages either as regards explosive force or aptitude of detonation.

Mixtures of Nitrate of Cupro-Ammonia and Nitrate of Ammonia.—Ammoniacal nitrate of copper, or nitrate of cupro-ammonia, is a salt which has the formula

$$N_2 O_5 Cu O, 4 N H_3 = 255{\cdot}5,$$

it is easily obtained in beautiful indigo-blue crystals, when a solution of nitrate of copper saturated with ammonia is evaporated to dryness. Under the action of heat this salt melts, and at the end of a certain time deflagrates on fusion, without producing any detonation, properly speaking.

The detonating properties of this composition, both alone and mixed with nitrate of ammonia, have been studied. It was found that the salt, either pure or mixed with 1⅔rds of its weight of nitrate of ammonia, freely detonates under the action of one fulminate of mercury detonator.

The specific gravity of the salt is 1·87.

It detonates very feebly under the hammer.

The heat of dissolution in water is negative and equal to 60·6 calories per kilogramme, or 15·48 calories for the double equivalent weight of 255·5 grammes. The heat of dissolution in dilute nitric acid of 2·2 calories, is 53 calories per kilogramme, or 13·54 calories for the double equivalent weight.

From this last value, combined with those which are given in Mr. Berthelot's tables (Annuaire du Bureau des Longitudes, 1888), the heat of decomposition of the salt into its gaseous elements, Cu O being supposed unaltered, may be easily deduced. Thus:—

Heat of formation,		4 $(N+H_3)$ dissolved … … …	84·0
Do.	do.	(N_2+O_5) dissolved … … …	28·6
Do.	do.	$(Cu\,O+N_2\,O_5)$ … … … …	15·0
Do.	do.	$(N_2\,O_5+4\,N\,H_3)$ … … …	50·0
Total … … … … … … … …			177·6
Heat of dissolution in dilute nitric acid … … …			13·5
Heat of formation $(N_6+H_{12}+O_5+Cu\,O)$ … … …			164·1

From this number, combined with that of the heat of dissolution in water, it follows:

$N_2\,O_5\,Cu\,O$ (dissolved) + 4 $N\,H_3$ (dissolved) = 20·77 calories.

$N_2\,O_5\,Cu\,O + 6\,H_2\,O$ (solid) + 4 $N\,H_2$ (gaseous)

= $N_3\,O_3\,Cu\,O$, 4 $N\,H_3$ (solid) + 6 H_2 (solid) disengages 69·28 calories.

The products of its decomposition have not been examined. The mode of decomposition which would disengage the maximum of heat corresponds to the formula,

$$N_2\,O_5,\ Cu\,O,\ 4\,N\,H_3 = 3\,N_2 + H_2 + 5\,H_2O + Cu\ O,$$

assuming that the Cu O remains unaltered, and would disengage 131·8 calories (volume constant water gaseous) for 255·5 grammes or 516 calories per kilogramme.

When the salt is detonated unconfined, abundant white fumes of nitrate of ammonia and nitrous vapours are produced and observed. The mode of decomposition which then occurs cannot be stated with certainty.

Complete combustion with nitrate of ammonia occurs according to the formula

$$N_2\,O_5,\ Cu\,O,\ 4\,N\,H_3 + \tfrac{1}{2}\,(N_2\,O_5,\ N_2\,H_8\,O) = 4\,N_2 + 8\,H_2\,O + Cu\,O.$$

The proportions in which the two salts should be mixed is, therefore, 76 of the copper salt, and 24 nitrate of ammonia.

The amount of heat disengaged by combustion is 655·5 calories per kilogramme. By the ordinary method, and taking into account the specific heat of oxide of copper (which is 11·22 with Cu O=70) the following figures are easily found:—

$$Q_k = 655{\cdot}5,\ t = 1{,}750°C,\ f = 6{,}090,\ a = 0{\cdot}796.$$

The temperature of detonation being relatively low, the Commission thought that this mixture, either alone or with the addition of nitrate of ammonia, might constitute an explosive which might be found safe for use in fiery mines.

Calorimetrical experiments on its detonation were made in the boiler, filled with air, as shewn in the annexed table:

The unconfined detonation of the pure salt, although it certainly leaves no residue, yields an amount of heat much less than that which would correspond to complete detonation. The production of the white and nitrous fumes previously mentioned shews that a different reaction occurs.

The unconfined detonation of the mixtures with nitrate of ammonia is also very incomplete, and becomes almost nil when the proportion of nitrate of ammonia amounts to double that of the cupric salt.

In tin tubes the decomposition is still incomplete; from the pure salt, as far as the mixture of 10 of salt with 90 of nitrate of ammonia, the heat disengaged remains nearly equal to three-fourths of the theoretical quantity. It may, therefore, be assumed that in a shot hole the decomposition will be sufficiently complete.

Fusion, like compression, hinders the detonation.

Nature of Explosive.	Weight of Cartridge.	Method of using the Explosive.	Pressure of Water Column.		Q deduced for 1,543·2 grains.		Remarks.
			Metres.	Inches.	Observed.	Calculated.	
	Grains.					(*)	
Cupro. amm.	771·6	Paper.	0·16	6·30	19	53	Salt—very dry.
Do.	771·6	in. in. Tin, 0·98 and 1·22	0·225	8·86	34	53	do.
Do.	771·6	in. in. Tin, 0·98 and 1·57	0·21	8·27	38	53	do.
Do.	771·6	do.	0·19	7·48	34	53	Salt—a little damp.
75 cupro, 25 nitrate...	771·6	Paper.	0·21	8·27	25	67	do.
75 do. , 25 do. ...	771·6	in. in. Tin, 0·98 and 1·22	0·29	11·42	52	67	do.
33 do. , 67 do. ...	771·6	Paper.	0·00	0·00	—	51	do.
33 do. , 67 do. ...	347·2	do.	0·03	1·18	—	51	Salt—very dry.
33 do. , 67 do. ...	771·6	in. in. Tin, 0·98 and 1·57	0·21	8·27	39	51	Salt—a little damp.
20 do. , 80 do. ...	771·6	do.	0·16	6·30	29	46	do.
20 do. , 80 do. ...	771·6	do.	0·11	4·33	20	46	Material dry, melted, and powdered.
20 do. , 80 do. ...	771·6	do.	0·10	3·94	18	46	Material dry, melted, and powdered, very fine.
20 do. , 80 do. ...	771·6	do.	0·19	7·48	34	46	Mixture, powdered very dry.
20 do. , 80 do. ...	771·6	do.	0·11	4·33	20	46	Mixture, compressed under 15 atmospheres.
10 do. , 90 do. ...	771·6	do.	0·16	6·30	29	42	Salt—a little damp.

It is certain that these mixtures require for detonation, detonators containing at least 23·15 grains of fulminate.

In a shot-hole 40 inches deep, drilled at Sevran in the midst of argillaceous rock, a cartridge of 3,086·5 grains of the complete combustion mixture produced a chamber of compression whose principal dimensions were 1 foot 11·62 inches × 1 foot 5·72 inches × 1 foot 5·72 inches.

Under the same conditions a cartridge of 3,086·5 grains of the mixture of 33 of nitrate of cupro-ammonia with 66 of nitrate of ammonia produced a chamber 11·81 inches × 11·81 inches × 11·81 inches.

(*) Calculated, assuming the decomposition to be complete, with mutual reactions of the gaseous products.

Experiments made in fire-damp yielded the following results :—

Nature of Explosive.	Weight of Cartridge.					
	1,543·2 Grains.			3,086·5 Grains.		
	Pressure of Water Column.		Result.	Pressure of Water Column.		Result.
	Metres.	Inches.		Metres.	Inches.	
Cupro. amm.	0·18	7·09	N	—	—	I
75 cupro. amm., 25 nitrate... ...	0·30	11·81	N	0·36	14·17	N
75 do. , 25 do.	—	—	—	0·30	11·81	N
75 do. , 25 do.	—	—	—	0·60	23·62	N
33 do. , 66 do.	—	—	—	0·24	9·45	N
33 do. , 66 do.	—	—	—	0·12	4·72	N
20 do. , 80 do.	—	—	—	0·04	1·57	N
10 do. , 90 do.	0·00	0·00	N	—	—	—

A cartridge of 1,543·2 grains of the mixture of 20 of the salt with 80 of ammonia nitrate in a tin tube 0·93 inch and 1·22 inches on detonation produced a pressure of 8·66 inches of water without igniting the fire-damp.

The experiments have, therefore, been thoroughly satisfactory, when unconfined, in fire-damp, for mixtures, even the most explosive of the cuprous salt and nitrate of ammonia.

Experiments were next made in a mixture of air containing 10·3 per cent. of coal-gas. The results have been as follows :—

Nature of Explosive.	Weight of Cartridges.								
	956·8 Grains.			1,543·2 Grains.			3,086·5 Grains.		
	Pressure of Wtr. Clmn.		Rslt.	Pressure of Wtr. Clmn.		Rslt.	Pressure of Wtr. Clmn.		Rslt.
	Mtrs.	Ins.		Mtrs.	Ins.		Mtrs.	Ins.	
Cupro. amm.	—	—	—	—	—	I	—	—	—
75 cupro. amm., 25 nitrate... ...	—	—	—	0·12	4·72	N	—	—	—
75 do. , 25 do.	—	—	—	0·18	7·09	N	—	—	—
33 do. , 66 do.	0·0	0·0	N(*)	—	—	—	—	—	I
33 do. , 66 do.	—	—	I (†)	—	—	—	—	—	—
20 do. , 80 do.	—	—	—	0·04	1·57	N	0·16	6·30	N
20 do. , 80 do.	—	—	—	0·04	1·57	N	—	—	—

(*) Explosive placed in a thin brass case which shut by a cover carrying a socket for the detonator.

(†) Explosive placed in a thin brass case without a cover.

The mixture of 75 parts did not ignite coal-gas with 1,543·2 grains cartridges.

The mixture of 33 parts ignited with a 3,086·5 grains cartridge, and with a 956·8 grains cartridge placed in a brass case open at the top. The singular fact was observed that the ignition of the gaseous mixture occurred one or two seconds after the detonation of the cartridge.

The mixture of 20 parts did not ignite either with 1,543·2 grains or 3,086·5 grains cartridges.

It should be remembered that these experiments were made in a gaseous mixture notably more inflammable than the fire-damp mixture, and as the experiments made in fire-damp did not produce ignition even with mixtures of 75 parts, and cartridges of 3,086·5 grains, it seems that the mixture of nitrate of ammonia with nitrate of cupro-ammonia should be considered to possess very satisfactory guarantees of safety whenever the proportion of nitrate of ammonia reaches 25 parts per hundred.

The mixture containing 80 per cent. of nitrate of ammonia, which is proved safe, even in coal-gas, with two cartridges of 3,086·5 grains, detonates at a temperature of 2,372 degs F., and possesses a force *f* equal to about 5,500 kilogrammes.

Experiments on detonation, made in a bomb by Mr. Vieille, have given the following results :—

NATURE OF EXPLOSIVE.	Density of Charging. Δ	PRESSURE.	
		Observed.	Theoretical.
Cupro-amm....	0·2	1,402	(*) 1,355
Do.	0·3	2,221	2,240
Cupro-amm., and nitrate (mixture giving complete combustion)	0·2	1,455	1,450
Do. do.	0·2	1,490	,,
Do. do.	0·3	2,346	2,400
Do. do.	0·3	2,290	,,
20 cupro-amm., 80 nitrate	0·2	1,115	1,340
20 do. , 80 do.	0·3	2,143	2,260

The combustion is always slow enough if the rupture is static.

The firing has been effected through the intermediary of a detonator of 15·43 grains of extra-fine powder; to allow for this, the observed figures have been reduced by 150 kilogrammes when Δ = 0·2 and 200 kilogrammes when Δ = 0·3.

CONCLUSIONS.

The new facts which are herein explained, confirm the conclusions of the first report, and allow their definition and completion.

The normal temperature of ignition of fire-damp mixtures is known within 90 degrees F., but it is necessary that the effect of that temperature should be prolonged for some time in order that ignition may be produced.

The new experiments, in harmony with the previous ones, shew that, owing to

---

(*) It is assumed that the decomposition occurs according to the formul $3 N_2 + 6 H_2O + Cu$

the retardation of ignition characteristic of fire-damp mixtures, owing also to the almost instantaneous mixture of the gases resulting from detonation with the surrounding air, and to the quick cooling consequent thereupon, explosives whose temperature of detonation is less than about 3,992 degs. F., are incapable of igniting fire-damp mixtures when detonated under the normal conditions of their use, that is, in holes properly stemmed. The stemming, made with care, should always be vigorously enforced as one of the most essential conditions of safe blasting.

The guarantees of safety diminish, all things being constant in proportion as the stemming becomes more imperfect. At the limit, and when the cartridge detonates unconfined without envelope, the conditions of safety cannot be formulated with any exactitude.

Safety would doubtless be still ensured completely, if the explosive consisted of one substance only, whose detonation would develop a temperature sufficiently low and only yield incombustible products. Unfortunately, nitrate of ammonia is, as yet, the only substance known which realises these conditions, and its facility of detonation appears insufficient.

Resort must, therefore, be made to mixtures, at least dual, and which are never absolutely intimate, whatever may be the precautions taken. Now, if one of the mixed substances is combustible, or when detonated alone, is susceptible either of developing a temperature higher than 3,992 degs. F., or of giving off combustible gaseous products, it may always be feared that a particle of that substance, placed on the surface of the cartridge, may happen, at the time of detonation, to ignite the exterior gas. Such is doubtless the cause of the irregularities which occur in the ignition of fire-damp by the unconfined detonation of the same mixture.

These ignitions, in a way accidental, are the more to be dreaded, as the substance which may produce them is used in higher proportions, as the mixture is less intimate, and as the surface or (which is nearly the same thing) as the weight of the cartridge increases.

The only means by which this happily secondary cause of danger may be avoided, is to ensure the utmost perfection in mixing, and to diminish as far as possible without too greatly reducing the facility of detonation and the power of the explosive, the proportion of the substance capable of igniting the gas.

Besides it is important to remark that safety in the use of explosives in the midst of a fire-damp atmosphere depends, as has been previously mentioned, upon the almost instantaneous mixture of the gases of the detonation with a sufficient volume of surrounding air. It would, therefore, be dangerous to fire shots in a too limited space, and with a weight of explosive too great for the volume of the surrounding air as compared with that of the gases of detonation.

These various considerations justify the recommendation given by the Commission in the first report, and which is repeated verbatim. (*)

"4. By reason of the complexity and the lack of certainty of the phenomena which may attend the detonation of unconfined explosives, it will always be prudent to avoid firing shots (even charged with one of the explosives considered the safest) at a point where the mixture of fire-damp and air may be inflammable. The choice of these explosives should be considered as considerably lessening the danger of explosion; it should not be considered as absolutely suppressing it."

In the present state of knowledge, the dual mixtures which may be used as explosives, suitable for ensuring the safety of fiery mines, necessarily contain nitrate of ammonia as one of their elements, and can be divided into two categories.

(*) See page 43

I. Nitrate of ammonia may be mixed with a substance detonating at a high temperature, but yielding incombustible products, nitro-glycerine for example. Safety appears to be sufficiently assured when, the nitro-glycerine being used in the state of dynamite, the proportion of dynamite does not exceed 30 per cent. Two cartridges of 3,086·5 grains, containing 30 parts of dynamite, with 70 parts of nitrate, were detonated unconfined in a fire-damp mixture without igniting it. Cartridges of 771·6 grains, 1,543·2 grains, and 3,086·5 grains of a mixture containing 20 parts of dynamite and 80 parts of nitrate, did not produce ignition of the fire-damp. A cartridge of 771·6 grains of the same explosive can even be detonated unconfined, in a mixture of air and coal gas, without igniting it.

II. Nitrate of ammonia can also be mixed with a substance, combustible in itself or yielding combustible products on detonation.

Mixtures of this nature should satisfy the following conditions :—

Develop a temperature of detonation as low as possible, and in all cases less than 3,992 degs. F. ;

Not yield combustible gases after complete detonation ;

Possess sufficient explosive force so as to avoid the use of great weights of explosive ;

Possess a great facility of detonation, at least in a stemmed hole, so that the proportion of missed shots may be unimportant ;

Capable of preservation for a long time, against all changes ;

Lastly, be capable of sale to the users at a not too high price.

Among the numerous mixtures based on nitrate of ammonia, fulfilling more or less completely all these conditions, and which the Commission has tested, those which ought apparently to be mentioned in preference are as follows :—

(1). Mixtures containing at the most 75 parts of nitrate of cupro-ammonia, this maximum proportion, detonating unconfined, has neither ignited fire-damp with cartridges of 3,086·5 grains (3 expts.) nor coal-gas with cartridges of 1,543·2 grains (2 expts.) ;

(2). The mixture containing 6 parts of naphthalene, which, detonating unconfined, did not ignite either fire-damp with cartridges of 3,086·5 grains (2 expts.) or coal-gas with cartridges of 771·6 grains (2 expts.) ; and only ignited coal-gas with cartridges of 3,086·5 grains ;

(3). The mixture containing 15 parts of octonitric cotton, which, detonating unconfined, did not ignite fire-damp with cartridges of 3,086·5 grains (2 expts.) ;

(4). The mixture containing 10 parts of mononitronaphthalene, which, detonating unconfined, in five experiments made with cartridges of 925·9 grains, 1,543·2 grains, and 3,086·5 grains, only once ignited the fire-damp with a cartridge of 925·9 grains ;

(5). The mixture containing 10 parts of dinitro-benzol, which, detonating unconfined, did not ignite fire-damp with cartridges of 1,543·2 grains (4 expts.), and with cartridges of 3,086·5 grains, only ignited it once in three experiments.

Practical trials made in the mine, and which are now being made, can alone enable mine-owners to choose between the various explosives.

8th November, 1888.

The President of the Sub-Commission and Reporter,

ER. MALLARD.

Adopted by the Commission at their sitting of the 8th November, 1888.

P. VIEILLE, Secretary. BERTHELOT, President.

TABLE OF EXPERIMENTS MADE AT THE SEVRAN-LIVRY POWDER MILL.

FROM JUNE TO OCTOBER, 1888.

A. EXPERIMENTS MADE IN COMBUSTIBLE GASES.

Dates.	Nature of Explosive. (*)	Weight of Explosive.	Weight of Fulminate.	Pressure of Water Column. (†)		Result of Experiment. (‡)	Remarks.
I. COMBUSTIBLE GASES, CONTAINING ·103 OF FIRE-DAMP AND ·897 OF AIR, BY VOLUME.							
1. DETONATORS.							
		Grs.	Grs.	Metr.	Inches.		
9 July	3 plugged detonators	...	69·45	...	...	N	One detonator closed by the plug carrying the electric wire.
6 Aug. (2)	Military detonator	...	?	...	...	I	
2. DYNAMITE AND NITRATE OF AMMONIA.							
30 June (1)	10 dynamite, 90 nitrate	771·6	23·15	·10	3·94	N	
30 June (2)	20 dynamite, 80 nitrate	771·6	23·15	,,	,,	N	
9 July (1)	do.	771·6	23·15	,,	,,	N	
28 July (1)	do.	1,543·2	23·15	·15	5·91	N	
28 July (2)	do.	1,543·2	23·15	·34	13·39	N	
30 July (1)	do.	1,543·2	23·15	·28	11·02	N	
11 Aug. (2)	do.	3,086·5	23·15	·45	17·72	N	
11 Aug. (3)	do.	3,086·5	23·15	·44	17·32	N	
23 July (1)	30 dynamite, 70 nitrate	771·6	23·15	·22	8·66	N	
23 July (2)	do.	1,543·2	23·15	·62	24·41	N	
25 July (1)	do.	1,543·2	23·15	·40	15·75	N	
11 Aug. (2)	do.	3,086·5	23·15	·62	24·41	N	
11 Aug. (2)	do.	3,086·5	23·15	>1·00	> 39·37	N	
28 July (1)	40 dynamite, 60 nitrate	771·6	23·15	,,	,,	N	
28 July (2)	do.	771·6	23·15	·30	11·81	N	
25 July (1)	do.	1,543·2	23·15	,,	,,	I	
9 July (1)	50 dynamite, 50 nitrate	771·6	23·15	·44	17·32	N	
28 July (1)	do.	771·6	23·15	,,	,,	N	
30 June (1)	do.	771·6	23·15	,,	,,	I	
30 June (1)	do.	771·6	23·15	,,	,,	I	
11 July (2)	do.	1,543·2	23·15	,,	,,	I	
28 July (1)	60 dynamite, 40 nitrate	771·6	23·15	·48	18·90	N	
6 Aug. (1)	80 dynamite, 20 nitrate	1,543·2	23·15	,,	,,	I	
25 Oct. (9)	100 dynamite, 0 nitrate	771·6	23·15	,,	,,	I	Tin tube of 0·98 in. and 1·22 in. diam.

(*) The cartridge is exposed or merely wrapped in paper, and the explosive is powdered, unles the contrary is expressly stated.

(†) P, *the pressure developed in the boiler after the detonation of the cartridge*, when the combustible gas has not been ignited. This pressure, expressed in metres of water, is observed about 15 seconds after the detonation; the observation is only approximate, and is only intended to give some idea of the more or less complete detonation of the explosive.

(‡) I signifies that the gaseous mixture was ignited; N signifies that there was not ignition of the gaseous mixture.

A. EXPERIMENTS MADE IN COMBUSTIBLE GASES.—*Continued.*

3. OCTONITRIC COTTON AND NITRATE OF AMMONIA.

Dates.	Nature of Explosive.	Weight of Explosive.	Weight of Fulminate.	Pressure of Water Column.		Result of Experiment.	Remarks.
		Grs.	Grs.	Metr.	Inches.		
11 Aug. (2)	15 cotton, 85 nitrate	3,086·5	23·15	·60	23·62	N	
11 Aug. (3)	do.	3,086·5	23·15	>1·00	> 39·37	N	
23 July (1)	20 cotton, 80 nitrate	771·6	23·15	·30	11·81	N	
23 July (2)	do.	1,543·2	23·15	·50	19·68	N	
25 July (1)	do.	1,543·2	23·15	·28	11·02	N	
30 July (3)	do.	1,543·2	23·15	,,	,,	N	
30 July (3)	do.	1,543·2	23·15	·44	17·32	N	
30 July (3)	do.	1,543·2	23·15	·40	15·75	N	
6 Aug. (3)	do.	1,543·2	23·15	·52	20·47	N	
30 July (2)	do.	1,543·2	23·15	,,	,,	I	
11 Aug. (2)	do.	3,086·5	23·15	,,	,,	I	
11 Aug. (3)	do.	3,086·5	23·15	,,	,,	I	
11 July (2)	30 cotton, 70 nitrate	463·0	23·15	·04	1·57	N	
23 July (2)	do.	1,543·2	23·15	·62	24·41	N	
25 July (2)	40 cotton, 60 nitrate	1,543·2	23·15	,,	,,	I	
27 June (2)	60 cotton, 40 nitrate	463·0	23·15	,,	,,	I	
9 July (1)	100 cotton, 0 nitrate	463·0	23·15	·18	7·09	N	
9 July (2)	do.	463·0	23·15	·18	7·09	N	
11 July (2)	do.	463·0	23·15	,,	,,	I	

4. NONONITRIC COTTON (MINING COTTON) AND NITRATE OF AMMONIA.

6 Aug. (3)	15 cotton, 85 nitrate	1,543·2	23·15	·50	19·68	N	
6 Aug. (1)	do.	1,543·2	23·15	,,	,,	I	

5. MONONITRONAPHTHALENE AND NITRATE OF AMMONIA.

11 July (1)	9 m. n. naphtha, 91 nitrate	463·0	23·15	·06	2·36	N	Substance powder'd
9 July (1)	do.	771·6	23·15	·22	8·66	N	do.
9 July (2)	do.	771·6	23·15	·26	10·24	N	do.
9 July (2)	do.	771·6	69·45	·26	10·24	N	do.
25 July (2)	do.	1,543·2	23·15	·00	0·00	N	do.
30 July (2)	do.	1,543·2	23·15	·00	0·00	N	do.

A. EXPERIMENTS MADE IN COMBUSTIBLE GASES.—*Continued.*

Dates.	Nature of Explosive.	Weight of Explosive.	Weight of Fulminate.	Pressure of Water Column.		Result of Experiment.	Remarks

6. NAPHTHALENE AND NITRATE OF AMMONIA.

		Grs.	Grs.	Metr.	Inches.		
15 Sept. (1)	6 naphthalene, 94 nitrate	1,543·2	23·15	·04	1·57	N	
15 Sept. (1)	do.	3,086·5	23·15	·07	2·76	N	
15 Sept. (1)	do.	3,086·5	69·45	·10	3·94	N	
15 Sept. (1)	do.	1,821·0	23·15	·16	6·30	N	In tin tube 0·98 in. and 1·22 in.
15 Sept. (1)	do.	1,157·4	23·15	·20	7·87	N	do.

7. DINITROBENZOL AND NITRATE OF AMMONIA.

2 July (2)	10 dinitro, 90 nitrate	1,543·2	23·15	·44	17·32	N	
6 Aug. (3)	do.	1,543·2	23·15	·32	12·60	N	
6 Aug. (3)	do	1,543·2	23·15	·32	12·60	N	
6 Aug. (3)	do.	1,543·2	23·15	·32	12·60	N	
11 Aug. (1)	do.	3,086·5	23·15	·00	0·00	N	
11 Aug. (3)	do.	3,086·5	23·15	·50	19·68	N	
11 Aug. (1)	do.	3,086·5	23·15	,,	,,	I	
9 July (1)	15 dinitro, 85 nitrate (Bellite)	617·3	23·15	·24	9·45	N	
27 June (2)	do.	771·6	23·15	,,	,,	N	
9 July (2)	do.	771·6	23·15	·20	7·87	N	
30 July (2)	do.	1,543·2	23·15	·52	20·47	N	
30 July (1)	do.	1,543·2	23·15	,,	,,	I	
30 June (2)	20 dinitro, 80 nitrate	771·6	23·15	,,	,,	N	
25 July (1)	do.	1,543·2	23·15	·50	19·68	N	

8. PICRATE OF AMMONIA AND NITRATE OF AMMONIA.

8 Oct. (1)	10 picrate, 90 nitrate	3,086·5	23·15	·18	7·09	N	
8 Oct. (1)	do.	3,086·5	23·15	·17	6·69	N	
8 Oct. (1)	20 picrate, 80 nitrate	3,086·5	23·15	,,	,,	I	

9. RESIN AND NITRATE OF AMMONIA.

10 Oct. (1)	10 resin, 90 nitrate	3,086·5	23·15	·09	3·54	N	
10 Oct. (2)	do,	3,086·5	23·15	·09	3·54	N	
10 Oct. (2)	do.	3,086·5	23·15	·05	1·97	N	

A. Experiments made in Combustible Gases.—*Continued.*

10. Coal Tar and Nitrate of Ammonia.

Dates.	Nature of Explosive.	Weight of Explosive.	Weight of Fulminate.	Pressure of Water Column.		Result of Experiment.	Remarks.
		Grs.	Grs.	Metr.	Inches.		
10 Oct. (1)	12 tar, 88 nitrate	3,086·5	23·15	·10	3·94	N	Mixture not heated
10 Oct (1)	do.	3,086·5	23·15	·50	19·68	N	do.
8 Oct. (2)	do.	3,086·5	23·15	,,	,,	I	do.
10 Oct. (1)	do.	3,086·5	23·15	·06	2·36	N	Mixture heated for 2 hours at 149° F.
10 Oct. (1)	do.	3,086·5	23·15	·06	2·36	N	do.
10 Oct. (1)	8 tar, 92 nitrate	3,086·5	23·15	·60	23·62	N	Mixture heated for 1 hour at 149° F.
10 Oct. (1)	do.	3,086·5	23·15	·58	22·83	N	do.
10 Oct. (1)	do.	3,086·5	23·15	,,	,,	I	do.

11. Heavy Coal Oil and Nitrate of Ammonia.

8 Oct. (2)	10 oil, 90 nitrate	3,086·5	23·15	·00	0·00	N	
8 Oct. (2)	do.	3,086·5	23·15	·00	0·00	N	

12. Nitrate of Cupro-Ammonia and Nitrate of Ammonia.

25 Oct. (1)	10 cupro-ammonia, 90 nitrate	1·543·2	23·15	·00	0·00	N	
25 Oct. (2)	20 cupro-ammonia, 80 nitrate	3,086·5	23·15	·04	1·57	N	
25 Oct. (3)	do.	1,543·2	23·15	·22	8·66	N	Tin tube ·98 inch and 1·22 inches.
25 Oct. (4)	33 cupro-ammonia, 66 nitrate	3,086·5	23·15	·24	9·45	N	
25 Oct. (5)	75 cupro-ammonia, 25 nitrate	1,543·2	23·15	·30	11·81	N	
25 Oct. (6)	do.	3,086·5	23·15	·30	11·81	N	
25 Oct. (7)	do.	3,086·5	23·15	·36	14·17	N	
25 Oct. (8)	100 cupro-ammonia, 0 nitrate	1,543·2	23·15	·18	7·09	N	

II. Combustible Gases, containing ·103 of Coal-Gas and ·897 of Air, by Volume.

1. Dynamite and Nitrate of Ammonia.

27 July (2)	20 dynamite, 80 nitrate	771·6	23·15	·22	8·66	N	
27 July (1)	60 dynamite, 40 nitrate	771·6	23·15	·34	13·39	N	Lead tube 1·18 in and 1·38 in.
27 July (2)	70 dynamite, 30 nitrate	771·6	23·15	,,	,,	N	do.
27 July (2)	80 dynamite, 20 nitrate	771·6	23·15	·32	12·60	N	do.
27 July (1)	60 dynamite, 40 nitrate	771·6	23·15	·28	11·02	N	Tin tube 0·98 in. and 1·57 in.
27 July (1)	70 dynamite, 30 nitrate	771·6	23·15	·36	14·17	N	do.
27 July (1)	80 dynamite, 20 nitrate	771·6	23·15	·32	12·60	N	do.
27 July (1)	90 dynamite, 10 nitrate	771·6	23·15	·50	19·68	N	do.
4 May (1)	100 dynamite, 0 nitrate	771·6	23·15	,,	,,	I	do.
27 July (1)	do.	771·6	23·15	,,	,,	I	do.

A. EXPERIMENTS MADE IN COMBUSTIBLE GASES.—*Continued.*

Dates.	Nature of Explosive.	Weight of Explosive.	Weight of Fulminate.	Pressure of Water Column.		Result of Experiment.	Remarks.
	2. OCTONITRIC COTTON AND NITRATE OF AMMONIA.						
		Grs.	Grs.	Metr.	Inches.		
27 July (2)	20 cotton, 80 nitrate	771·6	23·15	,,	,,	I	
27 July (1)	10 cotton, 90 nitrate	771·6	23·15	·22	8·66	N	Tin tube 0·98 in. and 1·57 in.
27 July (1)	20 cotton, 80 nitrate	771·6	23·15	·28	11·02	N	do.
27 July (1)	30 cotton, 70 nitrate	771·6	23·15	·32	12·60	N	do.
27 July (2)	do.	771·6	23·15	·26	10·24	N	Lead tube 1·18 in. and 1·38 in.
	3. NAPHTHALENE AND NITRATE OF AMMONIA.						
30 Oct. (3)	6 naphthalene, 94 nitrate	771·6	23·15	·03	1·18	N	
30 Oct. (3)	do.	771·6	23·15	·03	1·18	N	
27 Oct. (1)	do.	3,086·5	23·15	·03	1·18	I	
27 Oct. (1)	do.	771·6	23·15	·14	5·51	N	Tin tube 0·98 in. and 1·22 in.
	4. NITRATE OF CUPRO-AMMONIA AND NITRATE OF AMMONIA.						
30 Oct. (2)	20 cupro-ammonia, 80 nitrate	1,543·2	23·15	·04	1·57	N	
30 Oct. (2)	do.	1,543·2	23·15	·04	1·57	N	
30 Oct. (1)	do.	3,086·5	23·15	·16	6·30	N	
30 Oct. (1)	33 cupro-ammonia, 67 nitrate	3,086·5	23·15	,,	,,	I (*)	
30 Oct. (2)	do.	956·8	23·15	·00	0·00	N	Thin brass case, with socket for detonator.
30 Oct. (2)	do.	956·8	23·15	,	,,	I (†)	Thin brass case, without socket for detonator.
30 Oct. (3)	75 cupro-ammonia, 25 nitrate	1,543·2	23·15	·12	4·72	N	
30 Oct. (3)	do.	1,543·2	23·15	·18	7·09	N	
30 Oct. (3)	100 cupro-ammonia, 0 nitrate	1,543·2	23·15	,,	,,	I	
	5. VARIOUS EXPLOSIVES.						
4 May (1)	50 dynamite, 50 coal-dust	1,388·9	23·15	,,	,,	I	
4 May (3)	Nononitric cotton	463·0	23·15	,,	,,	I	Tin tube 0·98 in. and 1·57 in.
4 May (3)	Detonating cellulose string	,,	,,	,,	,,	N	2 ft. 3½ in. long.

(*) Ignition occurred about 2 seconds after the detonation of the cartridge.

(†) Ignition occurred about 1 second after the detonation of the cartridge.

B. EXPERIMENTS ON DETONATION IN THE CLOSED BOILER, CONTAINING AIR ONLY.

1. DYNAMITE AND NITRATE OF AMMONIA.

Dates.	Nature of Explosive. (*)	Nature of Covering of the Explosive. (†)	Weight of Explosive.	Weight of Fulminate.	Pressure of Water Column. (‡)		Remarks.
			Grs.	Grs.	M.	In.	
6 Aug. (2)	10 dynamite, 90 nitrate	Paper	771·6	23·15	·08	3·15	
11 Aug. (2)	20 dynamite, 80 nitrate	Brass tube	771·6	23·15	·15	5·91	
6 Aug. (3)	do.	Paper	771·6	23·15	·17	6·69	
9 Aug. (21)	do.	do.	771·6	61·73	·25	9·84	
11 Aug. (12)	do.	Tin 0·98 in. and 1·22 in.	771·6	23·15	·22	8·66	
9 Aug. (20)	do.	Tin 0·98 in. and 1·57 in.	771·6	7·72	·23	9·05	
9 Aug. (19)	do.	do.	771·6	15·43	·26	10·24	
6 Aug. (4)	30 dynamite, 70 nitrate	Paper	771·6	23·15	·30	11·81	
6 Aug. (5)	40 dynamite, 60 nitrate	do.	771·6	23·15	·45	17·72	
6 Aug. (6)	50 dynamite, 50 nitrate	do.	771·6	23·15	·53	20·87	
27 Sept. (5)	60 dynamite, 40 nitrate	Brass tube	771·6	23·15	·41	16·14	
27 Sept. (8)	do.	do.	771·6	23·15	·40	15·75	
27 Sept. (6)	do.	Tin 0·98 in. and 1·22 in.	771·6	23·15	·45	17·72	
27 Sept. (7)	do.	Tin 0·98 in. and 1·57 in.	771·6	23·15	·37	14·57	
24 Sept. (6)	70 dynamite, 30 nitrate	Paper	385·8	23·15	·34	13·39	
24 Sept. (7)	do.	Tin 0·98 in. and 1·22 in.	771·6	23·15	·53	20·87	
24 Sept. (8)	do.	Tin 0·98 in. and 1·57 in.	771·6	23·15	·47	18·50	
24 Sept. (9)	do.	Tin 0·98 in. and 1·77 in.	771·6	23·15	·45	17·72	
27 Sept. (2)	do.	Brass case	771·6	23·15	·43	16·93	
24 Sept. (3)	80 dynamite, 20 nitrate	Paper	385·8	23·15	·38	14·96	
24 Sept. (4)	do.	Tin 0·98 in. and 1·22 in.	771·6	23·15	·59	23·23	
24 Sept. (5)	do.	Tin 0·98 in. and 1·57 in.	771·6	23·15	·51	20·08	
24 Sept. (1)	90 dynamite, 10 nitrate	Paper	385·8	23·15	·41	16·14	
24 Sept. (2)	do.	Tin 0·98 in. and 1·57 in.	771·6	23·15	·52	20·47	
27 Sept. (9)	100 dynamite, 0 nitrate	Paper	771·6	23·15	·67	26·38	Plugged detonator placed in the detonator socket of the brass case.
27 Sept. (1)	do.	Brass case	771·6	23·15	·58	22·83	
22 Sept. (4)	do.	Tin 0·98 in. and 1·77 in.	771·6	23·15	·44	17·32	
22 Sept. (5)	do.	do.	771·6	23·15	·48	18·90	

(*) The explosive is powdered and forced in by hand, unless otherwise stated.

(†) When the cartridge is stemmed inside a lead or tin tube, the internal and external diameters are given in inches.

(‡) The initial indicated pressure is deduced by a graphic construction from the observation of the pressure at known intervals of time after the detonation. (See pages 27 and 37.)

B. EXPERIMENTS ON DETONATION IN THE CLOSED BOILER, CONTAINING AIR ONLY.—*Continued.*

2. OCTONITRIC COTTON AND NITRATE OF AMMONIA.

Dates.	Nature of Explosive.	Nature of Covering of the Explosive.	Weight of Explosive	Weight of Fulminate	Pressure of Water Column.		Remarks.
			Grs.	Grs.	M.	In.	
31 July (9)	10 cotton, 90 nitrate	Paper	771·6	23·15	·25	9·84	
31 July (10)	do.	Tin 0·98 in. and 1·57 in.	771·6	23·15	·27	10·63	
9 Aug. (12)	15 cotton, 85 nitrate	Paper	771·6	23·15	·16	6·30	
9 Aug. (14)	do.	do.	771·6	23·15	·09	3·54	Compr. to 25 atmos.
9 Aug. (11)	do.	Tin 0·98 in. and 1·57 in.	385·8	23·15	·19	7·48	
9 Aug. (13)	do.	do.	385·8	23·15	·15	5·91	Compr. to 50 atmos.
21 Aug. (7)	do.	do.	385·8	15·43	·14	5·51	
21 Aug. (6)	do.	do.	385·8	7·72	·12	4·72	
31 July (7)	20 cotton, 80 nitrate	Paper	463·0	23·15	·13	5·12	
11 Aug. (3)	do.	Brass case	771·6	23·15	·30	11·81	
23 July (1)	do.	Paper	771·6	23·15	·34	13·39	
25 July (1)	do.	do.	771·6	23·15	·38	14·96	
25 July (2)	do.	do	771·6	23·15	·38	14·96	
9 Aug. (10)	do.	do.	385·8	23·15	·19	7·48	
9 Aug. (22)	do.	do.	385·8	61·73	·21	8·27	
11 Aug. (13)	do.	Tin 0·98 in. and 1·22 in.	771·6	23·15	·34	13·39	
31 July (8)	do.	Tin 0·98 in. and 1·57 in.	463·0	23·15	·21	8·27	
9 Aug. (10)	do.	do.	385·8	23·15	·21	8·27	
9 Aug. (2)	do.	Paper	385·8	23·15	·055	2·16	Compr. to 100 atmos.
9 Aug. (4)	do.	do.	385·8	23·15	·125	4·92	„ 75 „
9 Aug. (6)	do.	do.	385·8	23·15	·06	2·36	„ 50 „
9 Aug. (8)	do.	do.	385·8	23·15	·12	4·72	„ 25 „
9 Aug. (1)	do.	Tin 0·98 in. and 1·57 in.	385·8	23·15	·065	2·56	„ 100 „
9 Aug. (3)	do.	do.	385·8	23·15	·04	1·57	„ 75 „
9 Aug. (5)	do.	do.	385·8	23·15	·11	4·33	„ 50 „
Sept. (10)	30 cotton, 70 nitrate	Paper	385·8	23·15	·19	7·48	
24 Sept. (11)	do.	Tin 0·98 in. and 1·22 in.	771·6	23·15	·45	17·72	
24 Sept. (12)	do.	Tin 0·98 in. and 1·57 in.	771·6	23·15	·42	16·54	
31 July (5)	35 cotton, 65 nitrate	Paper	463·0	23·15	·17	6·69	
31 July (6)	do.	Tin 0·98 in. and 1·57 in.	463·0	23·15	·26	10·24	
31 July (5)	40 cotton, 60 nitrate	Paper	463·0	23·15	·17	6·69	
31 July (6)	do.	Tin 0·98 in. and 1·57 in.	463·0	23·15	·26	10·24	
31 July (1)	70 cotton, 30 nitrate	Paper	771·6	23·15	·92	36·22	
31 July (2)	do.	Tin 0·98 in. and 1·57 in.	771·6	23·15	·37	14·57	
21 Aug. (3)	90 cotton, 10 nitrate	Tin 0·98 in. and 1·22 in.	463·0	23·15	·27	10·63	
9 July (1)	100 cotton, 0 nitrate	Paper	463·0	23·15	·52	20·47	
21 Aug. (2)	do.	Tin 0·98 in. and 1·22 in.	771·6	23·15	·39	15·35	
21 Aug. (1)	do.	Tin 0·98 in. and 1·57 in.	771·6	23·15	·28	11·02	

B. EXPERIMENTS ON DETONATION IN THE CLOSED BOILER, CONTAINING AIR ONLY.—*Continued.*

Dates.	Nature of Explosive.	Nature of Covering of the Explosive.	Weight of Explosive.	Weight of Fulminate.	Pressure of Water Column.		Remarks.

3. DINITROBENZOL AND NITRATE OF AMMONIA.

Dates.	Nature of Explosive.	Nature of Covering of the Explosive.	Weight of Explosive.	Weight of Fulminate.	Pressure of Water Column.		Remarks.
			Grs.	Grs.	M.	In.	
11 Aug. (4)	10 dinitro, 90 nitrate	Brass case	771·6	23·15	·20	7·87	
9 Aug. (18)	do.	Paper	385·8	23·15	·16	6·30	
9 Aug. (16)	do.	do.	385·8	23·15	·06	2·36	Compr. to 25 atmos.
11 Aug. (11)	do.	Tin 0·98 in. and 1·22 in.	771·6	23·15	·30	11·81	
9 Aug. (15)	do.	Tin 0·98 in. and 1·57 in.	385·8	23·15	·18	7·09	
21 Aug. (9)	do.	do.	385·8	15·43	·12	4·72	
21 Aug. (8)	do.	do.	385·8	7·72	·09	3·54	
9 Aug. (15)	do.	do.	385·8	23·15	·11	4·33	Compr. to 25 atmos.

4. MONONITRONAPHTHALENE AND NITRATE OF AMMONIA (FAVIER EXPLOSIVE).

Dates.	Nature of Explosive.	Nature of Covering of the Explosive.	Weight of Explosive.	Weight of Fulminate.	Pressure of Water Column.		Remarks.
11 July (1)	9 mono. naph., 91 nitr.	Brass case	771·6	23·15	·27	10·63	
11 July (2)	do.	Tin 0·98 in. and 1·57 in.	771·6	23·15	·40	15·75	

5. NAPHTHALENE AND NITRATE OF AMMONIA.

Dates.	Nature of Explosive.	Nature of Covering of the Explosive.	Weight of Explosive.	Weight of Fulminate.	Pressure of Water Column.		Remarks.
21 Aug. (5)	6 naphth., 94 nitrate	Paper	771·6	23·15	·055	2·16	
30 Oct. (1)	do.	do.	771·6	23·15	·05	1·97	
30 Oct. (2)	do.	do.	3,086·5	23·15	·36	14·17	
18 Sept. (7)	do.	Tin 0·98 in. and 1·22 in.	771·6	23·15	·26	10·24	
21 Aug. (4)	do.	Tin 0·98 in. and 1·57 in.	771·6	23·15	·38	14·96	
30 Oct. (3)	do.	do.	771·6	23·15	·28	11·02	
22 Sept. (2)	do.	Tin 0·98 in. and 1·77 in.	771·6	23·15	·20	7·87	
22 Sept. (3)	do.	do.	771·6	23·15	·25	9·84	
27 Sept. (3)	do.	do.	771·6	23·15	·29	11·42	
18 Sept. (1)	10 naphth., 90 nitrate	Paper	771·6	23·15	·05	1·97	
18 Sept. (2)	do.	Tin 0·98 in. and 1·22 in.	771·6	23·15	·28	11·02	
18 Sept. (3)	do.	Tin 0·98 in. and 1·57 in.	771·6	23·15	·29	11·42	
18 Sept. (4)	20 naphth., 80 nitrate	Paper	771·6	23·15	·00	0·00	
18 Sept. (5)	do.	Tin 0·98 in. and 1·22 in.	771·6	23·15	·00	0·00	
18 Sept. (6)	do.	Tin 0·98 in and 1·57 in.	771·6	23·15	·035	1·38	

B. EXPERIMENTS ON DETONATION IN THE CLOSED BOILER, CONTAINING AIR ONLY.—*Continued.*

Dates.	Nature of Explosive.	Nature of Covering of the Explosive.	Weight of Explosive.	Weight of Fulminate.	Pressure of Water Column.		Remarks.
			Grs.	Grs.	M.	In.	
6. PICRATE OF AMMONIA AND NITRATE OF AMMONIA.							
8 Oct. (25)	10 picrate, 90 nitrate	Paper	771·6	23·15	·00	0·00	
8 Oct. (26)	do.	Tin 0·98 in. and 1·22 in.	771·6	23·15	·22	8·66	
8 Oct. (27)	do.	Tin 0·98 in. and 1·57 in.	771·6	23·15	·22	8·66	
8 Oct. (22)	20 picrate, 80 nitrate	Paper	771·6	23·15	·22	8·66	
8 Oct. (23)	do.	Tin 0·98 in. and 1·22 in.	771·6	23·15	·30	11·81	
8 Oct. (24)	do.	Tin 0·98 in. and 1·57 in.	771·6	23·15	·31	12·20	
8 Oct. (19)	28 picrate, 72 nitrate	Paper	771·6	23·15	·16	6·30	
8 Oct. (20)	do.	Tin 0·98 in. and 1·22 in.	771·6	23·15	·35	13·78	
8 Oct. (21)	do.	Tin 0·98 in. and 1·57 in.	771·6	23·15	·31	12·20	
8 Oct. (16)	40 picrate, 60 nitrate	Paper	771·6	23·15	·19	7·48	
8 Oct. (17)	do.	Tin 0·98 in. and 1·22 in.	771·6	23·15	·35	13·78	
8 Oct. (18)	do.	Tin 0·98 in. and 1·57 in.	771·6	23·15	·36	14·17	
8 Oct. (13)	50 picrate, 50 nitrate	Paper	771·6	23·15	·14	5·51	
8 Oct. (14)	do.	Tin 0·98 in. and 1·22 in.	771·6	23·15	·34	13·39	
8 Oct. (15)	do.	Tin 0·98 in. and 1·57 in.	771·6	23·15	·30	11·81	
8 Oct. (10)	60 picrate, 40 nitrate	Paper	771·6	23·15	·14	5·51	
8 Oct. (11)	do.	Tin 0·98 in. and 1·22 in.	771·6	23·15	·30	11·81	
8 Oct. (12)	do.	Tin 0·98 in. and 1·57 in.	771·6	23·15	·27	10·63	
8 Oct. (7)	100 picrate, 0 nitrate	Paper	771·6	23·15	·00	0·00	
8 Oct. (8)	do.	Tin 0·98 in. and 1·22 in.	771·6	23·15	·13	5·12	
8 Oct. (9)	do.	Tin 0·98 in. and 1·57 in.	771·6	23·15	·16	6·30	
7. HEAVY TAR OILS AND NITRATE OF AMMONIA.							
8 Oct. (4)	10 oil, 90 nitrate	Paper	771·6	23·15	·00	0·00	
8 Oct. (29)	do.	do.	771·6	23·15	·00	0·00	
8 Oct. (5)	do.	Tin 0·98 in. and 1·22 in.	771·6	23·15	·20	7·87	
8 Oct. (6)	do.	Tin 0·98 in. and 1·57 in.	771·6	23·15	·21	8·27	
8. COAL TAR AND NITRATE OF AMMONIA.							
8 Oct. (1)	12 tar, 88 nitrate	Paper	771·6	23·15	·00	0·00	The coal tar was not heated.
8 Oct. (28)	do.	do.	771·6	23·15	·00	0·00	
8 Oct. (2)	do.	Tin 0·98 in. and 1·22 in.	771·6	23·15	·09	3·54	
8 Oct. (3)	do.	Tin 0·98 in. and 1·57 in.	771·6	23·15	·12	4·72	
10 Oct. (3)	8 tar, 92 nitrate	Paper	771·6	23·15	·04	1·57	Dried for one hour at 149 degs. F.
10 Oct. (5)	do.	Tin 0·98 in. and 1·22 in.	771·6	23·15	·27	10·63	do.
10 Oct. (6)	do.	Tin 0·98 in. and 1·57 in.	771·6	23·15	·23	9·05	do.

B. EXPERIMENTS ON DETONATION IN THE CLOSED BOILER, CONTAINING AIR ONLY.—*Continued.*

Dates.	Nature of Explosive.	Nature of Covering of the Explosive.	Weight of Explosive.	Weight of Fulminate.	Pressure of Water Column.		Remarks.

9. NITRATE OF CUPRO-AMMONIA AND NITRATE OF AMMONIA.

			Grs.	Grs.	M.	In.	
25 Oct. (5)	10 cupr-amm., 90 nitr.	Tin 0·98 in. and 1·57 in.	771·6	23·15	·16	6·30	Cupric salt a little damp. Tin tube completely shattered by the explosive.
25 Oct. (4)	20 cupr-amm., 80 nitr.	do.	771·6	23·15	·16	6·30	Salt a little damp. Tin tube completely shattered by the explosive.
30 Oct. (8)	do.	do.	771·6	23·15	·11	4·33	Substance dried, melted, & powdered.
30 Oct. (9)	do.	do.	771·6	23·15	·10	3·94	Substance dried, melted, and powdered very fine.
30 Oct. (10)	do.	do.	771·6	23·15	·165	6·50	Simple mixture of substances, powdered and dried.
30 Oct. (11)	do.	do.	771·6	23·15	·01	0·39	Idem, compressed to 15 atmos.
25 Oct. (6)	33 cupr-amm., 67 nitr.	Paper	771·6	23·15	·00	0·00	Cupric salt a little damp.
30 Oct. (7)	do.	do.	347·2	23·15	·04	1·57	Cupric salt very dry.
25 Oct. (5)	do.	Tin 0·98 in. and 1·57 in.	771·6	23·15	·20	7·87	Cupric salt a little damp. Tube completely shattered.
25 Oct. (4)	75 cupr-amm., 25 nitr.	Paper	771·6	23·15	·22	8·66	Cupric salt a little damp.
25 Oct. (3)	do.	Tin 0·98 in. and 1·57 in.	771·6	23·15	·28	11·02	Idem. Tube completely shattered.
25 Oct. (2)	100 cupr-amm., 0 nitr.	Paper	771·6	23·15	·00	0·00	Salt a little damp.
30 Oct. (4)	do.	do.	771·6	23·15	·16	6·30	Salt very dry.
30 Oct. (5)	do.	Tin 0·98 in. and 1·22 in.	771·6	23·15	·225	8·86	Salt very dry.
30 Oct. (1)	do.	Tin 0·98 in. and 1·57 in.	771·6	23·15	·19	7·48	Salt a little damp.
30 Oct. (6)	do.	do.	771·6	23·15	·21	8·27	Salt very dry.

10. NITROMANNITE.

22 Sept. (6)	**Nitromannite**	**Paper**	**416·7**	**23·15**	**·44**	**17·32**	**Strongly compressed**
22 Sept. (7)	**do.**	**do.**	**385·8**	**23·15**	**·62**	**24·41**	**Powdered**
22 Sept. (8)	**do.**	**Tin 0·98 in. and 1·22 in.**	**385·8**	**23·15**	**·42**	**16·54**	**do.**
22 Sept. (9)	**do.**	**do.**	**385·8**	**23·15**	**·45**	**17·72**	**do.**
22 Sept. (10)	**do.**	**Tin 0·98 in. and 1·57 in.**	**385·8**	**23·15**	**·49**	**19·29**	**do.**
27 Sept. (4)	**do.**	**do.**	**617·3**	**23·15**	**·78**	**30·71**	**do.**
22 Sept. (11)	**do.**	**Tin 0·98 in. and 1·77 in.**	**385·8**	**23·15**	**·53**	**20·87**	**do.**

B. EXPERIMENTS ON DETONATION IN THE CLOSED BOILER, CONTAINING AIR ONLY.—*Continued.*

11. VARIOUS EXPLOSIVES.

Dates.	Nature of Explosive.	Nature of Covering of the Explosive.	Weight of Explosive.	Weight of Fulminate.	Pressure of Water Column.		Remarks.
			Grs.	Grs.	M.	In.	
6 Aug. (1)	15 mining cotton, 85 nitrate of amm.	Paper	771·6	23·15	·37	14·57	
11 July (3)	Nitrate of ammonia	Tin 0·98 in. and 1·57 in.	771·6	23·15	·025	0·98	
22 Sept. (1)	do.	Tin 0·98 in. and 1·77 in.	771·6	23·15	·14	5·51	
11 Aug. (10)	4 plugged detonators of 23·15 grs. ea.	Tin 0·98 in. and 1·57 in.	...	92·59	·015	0·59	

Issued MARCH, 1891.

NORTH OF ENGLAND INSTITUTE
OF
MINING AND MECHANICAL ENGINEERS.

Founded, 1852.—Incorporated by Royal Charter, 1876.

REPORT OF THE FRENCH COMMISSION ON THE USE OF EXPLOSIVES IN THE PRESENCE OF FIRE-DAMP IN MINES.

PART III AND LAST.

THIS REPORT, ALTHOUGH ISSUED TO ALL THE MEMBERS OF THE INSTITUTE BY ORDER OF THE COUNCIL, IS PRINTED PRIMARILY FOR THE USE OF THE EXPLOSIVES COMMITTEE.

Newcastle-upon-Tyne:
Printed for the Publishers by Andrew Reid, Sons & Co., 50, Grey Street.
1891.

SUBSCRIPTIONS.

The Annual Subscription of a Member is Two Guineas, of an Associate Member Two Guineas, of an Associate One Guinea, and of a Student One Guinea.

These Subscriptions are due and payable on the First Saturday of August in each year, in advance for the ensuing year, or immediately after election.

Forms for the nomination of New Members may be had on application to the Secretary.

On Change of Residence. Members will oblige by giving notice thereof to the Secretary, Neville Hall, Newcastle-upon-Tyne.

TRANSACTIONS.

Volumes I. to XXXVI. of the Transactions (excepting Vols. III., IV., V., VI., and XXI., which are out of print) can be had of the Publisher, price 21s. each.

Vol. XXIII., containing the large Map of the South Wales Coalfield, is published at 26s. Single Copies of the Map 10s. 6d.

DUPLICATES.

Notice is always given to Members in the first circular which is issued when a Part of the Transactions is published, and in the case of non-receipt immediate intimation should be given to the Secretary, as by the Rules of the Institute a duplicate copy can only be obtained by making a written application to the Council; and Parts cannot even then be had if they have been stitched together into volumes.

The following works published by the Institute are now ready:—

PRICE 21s., OR POST FREE 22s. 2D., A REPRINT OF

VOL. XVII. OF THE TRANSACTIONS OF THE INSTITUTE,

Containing the Report of the Committee on Haulage of Coal Underground.

In Paper Covers, uniform with the Transactions, 5s.; by Post, 5s. 6d.

A GENERAL INDEX TO VOLS. I. TO XXV.

OF THE TRANSACTIONS OF THE INSTITUTE.

Uniform in size with the Transactions,

A Catalogue of the Books and Maps in the Library

of the North of England Institute of Mining and Mechanical Engineers, 260 pp. Price—To Members, 5s.; to Non-Members, 10s. By Post, 5d. extra.

Royal 8vo, Price 25s. (by Post 25s. 9d.), Containing 64 Illustrations in Autotype,

ILLUSTRATIONS OF FOSSIL PLANTS.

Being an Autotype reproduction of Selected Drawings of Fossil Plants, prepared under the supervision of the late Dr. LINDLEY and Mr. W. HUTTON, between the Years 1835 and 1840. Edited by Professor G. A. LEBOUR, M.A., F.G.S.

Uniform in Size with the above, Price 8s., by Post 8s. 3d.,

A Catalogue of the Hutton Collection of Fossil Plants,

Including a Synoptical List of the Chief Carboniferous Species not in the Collection. By Professor G. A. LEBOUR, M.A., F.G.S.

Royal 8vo, Vol. I., 293 Pages. Vol. II., 332 Pages. Vol. III., 329 Pages. Vol. IV., 334 Pages.

Price—To Members 5s. per Volume, (except Volume I., 2s. 6d.); by Post 5s. 6d. To Non-Members, 7s. 6d. per Volume; by Post 8s.

VOL. I. **(A-B)**, VOL. II. **(C-E)**, VOL. III. **(F-K)**, AND VOL. IV. **(L-R)**

OF AN

Account of the Strata of Northumberland and Durham,

AS PROVED BY BORINGS AND SINKINGS.

This Work, when completed, will comprise the whole of the Borings and Sinkings belonging to the late JOHN WATSON, Esq., of Willington, Northumberland, bequeathed by WM. WATSON, Esq., High Bridge, Newcastle-on-Tyne, to the North of England Institute of Mining and Mechanical Engineers. A large number of Borings, &c., furnished by Members of the Institute, are added, forming a complete record of all that has been ascertained by these means of the Geological formation of the two counties of Northumberland and Durham.

☞ *For Officers of the Institute, 1890-91, and Dates of Meeting, see p. 3 of Wrapper.*

PRACTICAL EXPERIMENTS IN COLLIERIES

ON EXPLOSIVES COMMENDED BY THE

EXPLOSIVE SUBSTANCES COMMISSION.

SUMMARY OF THE REPORTS ON THE EXPERIMENTS.

By Er.' MALLARD.

An account of the experiments made by the Explosive Substances Commission, on the use of explosives in the presence of fire-damp was recently published. It may be remembered that the Commission arrived at conclusions which may be summarised as follows :—

(1). An explosive, whose detonation is due to the explosive wave, may be harmless in the presence of fire-damp, if its temperature of detonation be below the temperature of ignition of fire-damp. It is only necessary, although *not sufficient*, that the temperature of detonation should be less than 3,992 degs. F. The degree of safety becomes greater as the temperature of detonation falls below this figure ; and it may be sufficient when it is reduced to 2,732 degs. or 2,912 degs. F.

(2). The temperature of detonation of an explosive, *i.e.*, the temperature to which the detonation raises the products of the decomposition, may be approximately calculated when the chemical equation governing the decomposition is known, and also the amount of heat disengaged corresponding to it ; and when it is assumed that the specific gaseous heats vary with temperature according to the laws indicated by Messrs. Mallard and Le Chatelier.

(3). The explosives which, in the present state of knowledge, appear suitable for use in fiery mines are at least dual mixtures. One of the substances is intended to diminish the temperature of detonation ; and it is important, as regards the useful effect, that this substance should be itself an explosive ; consequently, nitrate of ammonia is used, whose temperature of detonation barely exceeds 1,832 degs. F.

Accepting these general principles, the Commission experimented with a number of mixed explosives, which complied with the conditions recognised as essential for safety, and expressed their desire that these mixtures should be tested in mines, in order to ascertain their practical value. The directors of the Government Powder Mills at once complied with their desire, and two successive parcels were sent to the managers of Anzin, Firminy, Blanzy, and Ronchamp collieries, who were desirous of carrying out the experiments proposed by the Commission.

The first of these parcels, sent during September, 1888, contained 22·05 pounds of each of the following mixtures :

I. 30 parts of dynamite (containing 25 per cent. of silica) and 70 parts of nitrate of ammonia ;

II. 10 parts of dinitrobenzol and 90 parts of nitrate of ammonia ;

III. 15 parts of octonitric gun-cotton and 85 parts of nitrate ammonia.

The second supply sent during January, 1889, contained 33·07 pounds of each of the following mixtures :

I. 20 parts of nitrate of cupro-ammonia and 80 parts of nitrate of ammonia ;

II. 70 parts of nitrate of cupro-ammonia and 30 parts of nitrate of ammonia ;

III. 5 parts of naphthalene and 95 parts of nitrate of ammonia ;

IV. 20 parts of dynamite (containing 25 per cent. of silica) and 80 parts of nitrate of ammonia.

These explosives were made up in cartridges of 771·6 and 1,543·2 grains, protected by a double wrapping of paper soaked in paraffin. The mine managers who were desirous of making the trials, were requested to compare the results obtained by the use of the new explosives, both in stone and in coal, with those obtained with dynamite and with powder, both as regards the bulk and the condition of the coal detached.

The reports addressed to the Commission from the mines at which the experiments were made, are published in detail. It was thought useful to preface them with this short note summarising the principal results obtained.

I.—MIXTURES CONTAINING EITHER NAPHTHALENE OR NITRATE OF CUPRO-AMMONIA.

The mixture composed of 5 parts of naphthalene and 95 parts of nitrate of ammonia shewed a decidedly deficient facility of detonation. The same defect occurred with the mixture containing 20 parts of nitrate of cupro-ammonia and 80 parts of nitrate of ammonia.

The mixture containing 70 parts of nitrate of cupro-ammonia and 30 parts of nitrate of ammonia caused several missed shots ; and the fear is specially mentioned that the cupreous vapours, disengaged by the detonation, may affect the health of the workmen.

II.—MIXTURES CONTAINING NITRO-GLYCERINE.

Mixtures of dynamite have in every case been considered as possessing a very satisfactory facility of detonation ; no missed shots have been reported, and detonation has been effected of the mixture of 20 parts of dynamite and 80 parts of nitrate of ammonia, by detonators containing 11·57 grains of fulminate, or with the *extra strong* detonators of the Dynamite Company.

The explosive power of these mixtures, compared with that of blasting-gelatine and dynamite no. 1, has been estimated as shewn in the following table :—

NATURE OF EXPLOSIVE.	ANZIN.		FIRMINY.	BLANZY.	RON-CHAMP.
	Trials in Blocks of Lead.	Trials in Stone.	Trials in Coal.	Trials in Stone.	Trials in Stone.
Blasting-gelatine	100·0	00·0	100·0	100·0	100·0
Dynamite no. 1	81·2	—	—	67·0	80·0
30 dynamite, 70 nitrate ...	54·8	75·0	57·0	76·0	77·6
20 dynamite, 80 nitrate ...	51·9	64·8	42·5	50·0	36·8

The Anzin experiments were made according to the well-known method, by placing 154·3 grains of the explosive, covered by a stemming of sand, 1·97 inches thick, in cylindrical cavities bored in the middle of a block of lead. After the explosion, the volume which the cavity occupied was measured, a volume which remains almost constant for each explosive fired, under the same conditions.

The ratios of the volumes thus measured for the various explosives, may be considered as giving the proportion of their explosive forces.

In the trials made in stone, the method adopted at Anzin, Firminy, and Blanzy, as will be seen from the appended reports, consisted in firing shots with the new explosives, and in estimating what charge of blasting-gelatine, for instance, would have been used to produce the same result. It is evident that, even assuming things at the best, accuracy could only be approached after a very large number of tests.

At Ronchamp, the system used, appears at first sight to be more exact. The new explosives, and no. 1 dynamite were used successively at the face of a stone drift. In each case, the charge employed and the mass of stone broken down were noted; by this means, with each explosive, the ratio of the mass detached and the weight of the charge used, could be compared. Unfortunately, this method of procedure is only exact if, for each substance, there was a certainty that each charge was so proportioned to the resistance as to obtain the maximum useful effect. For instance, in the experiments made with the mixture of 20 parts of dynamite and 80 parts of nitrate, the stone was exceptionally hard, and the shot-holes being drilled in the same manner, were charged with practically equal weights, both of the new explosive, and of no. 1 dynamite. The most feeble explosive was then certainly used at a disadvantage, and the ascertained useful effect was less than that which would probably have been observed, if, other things being equal, the charge of the dynamite-nitrate mixture had been increased in a proper proportion. This may be the true explanation of the very low value of the explosive force of the mixture of 20 parts of dynamite and 80 parts of nitrate, compared to that of no. 1 dynamite observed at Ronchamp, On the other hand, the explosive force of the mixture of 30 parts of dynamite and 70 parts of nitrate, ascertained in a very easily worked stone, may have been estimated too highly.

Under this uncertainty, it would perhaps be advisable to adhere provisionally to the results obtained by the experiments in blocks of lead, which show for the two mixtures, what is very probable, very little difference in explosive power, which appears to be a little more than half of that of blasting-gelatine, and to two-thirds of that of dynamite no. 1, and double that of compressed blasting-powder. The four reports are unanimous in stating, that no difficulty would be encountered in the practical employment of these mixtures of dynamite and nitrate of ammonia. The two mixtures shew only a very slight difference in explosive force, and, therefore, the one which affords the maximum of safety, that containing 20 parts of dynamite and 80 parts of nitrate, is the one which should be adopted, at least in the working of coal, which is the most dangerous.

The production of disagreeable fumes is recorded at Blanzy, Ronchamp, and Firminy. An explanation of this phenomenon was found at the Firminy colliery. The fumes were due to the paraffin, with which the double paper covering of the cartridge was saturated; and they disappeared when the outside paper was removed, and the paraffin adhering to the interior paper was scraped off.

Certain inconveniences were also experienced at Firminy, manifestly arising from the necessarily imperfect manufacture of the cartridges used. When manufactured on a commercial scale, probably these would disappear.

Mixtures of nitro-glycerine and nitrate of ammonia have already been tried at Anzin on a considerable scale.

A very interesting report (*) on this subject has been made by Mr. Francois, who superintends the underground workings at Anzin collieries. The Commission suggested (†) the advantage there would be in suppressing the silica (as an inert matter). At Anzin, a mixture of 12 parts of nitro-glycerine slightly gelatinised, and 88 parts of nitrate of ammonia has been used. According to calculations made at Anzin on the lines of those made by the Commission, the temperature of detonation of this mixture should be about 2,732 degs. F., or practically the same as that of the mixture of 20 parts of dynamite and 80 parts of nitrate. This substance has the advantage of being more plastic and a little denser (1·04 instead of 0·94). The explosive power is greater, and has been considered by the Anzin engineers from their experiments as equal to 111, that of dynamite no. 1 being 100, and that of blasting-gelatine 185. The substance detonates easily under the action of a detonator containing 11·57 grains of fulminate.

It is sold by the Dynamite Company at 1s. 6·3d. per pound. The price of blasting-gelatine is 2s. 1·8d. per pound, or 1s. 5·2d. per pound duty deducted. The nitrate of ammonia costs 4·3d. per pound; taking these figures, the selling price of the mixture should be 5·9d. per pound and 1s. 2·5d. per pound including duty.

Two tons of this explosive has already been employed at Anzin, and it has proved very satisfactory in the work of enlarging roads; no explosive is used at Anzin in getting coal.

In stone-work, for which the mixture of 12 parts of nitro-glycerine and 88 parts of nitrate is considered as rather light, it has been proposed to use mixtures containing 20 to 30 parts of gelatinised nitro-glycerine.

A note (‡) has been kindly forwarded by Mr. Viala, the director of the Liévin collieries (Pas-de-Calais). They use, under the name of *grisoutines* A and B, mixtures supplied by the Dynamite Company, and which appear to be:—(A.) a mixture of 20 parts of dynamite and 80 parts of nitrate of ammonia, and (B) a mixture of 12 parts of nitro-glycerine and 88 parts of nitrate of ammonia, but it appears that they have not been able to ascertain from the company the exact proportions of these mixtures.

It may be pointed out that serious consequences result from putting into the market explosive mixtures, under fancy names; it being impossible for the users to know either their composition or their proportions. Under these circumstances, the identity of the substance is in no way guaranteed by its name, and even the most lengthy experiments lose all their value, when the material with which they have been made is not exactly known. In the absence of legal enactment, which seems necessary, the managers of mines should *exact* from the manufacturers the precise composition of the explosives with which they are supplied.

Whatever this may be, neither of these last-mentioned explosives ignited a gaseous mixture containing 10 per cent. of coal-gas and air, when detonated, without stemming, at the bottom of a hole drilled in a block of steel; ignition has only occurred when the gaseous mixture contained 12 per cent. of coal-gas. In our opinion, these results should be considered as very satisfactory, if it be remembered that mixtures of air and coal-gas are more inflammable than those of air and fire-damp, and that the detonation of a cartridge, at the bottom of a shot-hole, without any stemming, appears nearly impossible, unless expressly intended by the workman.

It was found that the new explosives are easily used, and do not give off disagreeable fumes.

(*) Page 136. (†) Page 88. (‡) Page 141.

III.—MIXTURES CONTAINING EITHER GUN-COTTON OR DINITROBENZOL.

Mixtures containing 15 parts of octonitric cotton and 85 parts of nitrate of ammonia, and 10 parts of dinitrobenzol and 90 parts of nitrate of ammonia have been very variably estimated as regards their facility of detonation.

At Ronchamp, no missed shots are mentioned, the extra strong detonators of the Dynamite Company being used.

At Anzin, where plugged detonators containing 23·15 grains of fulminate were used, only one missed shot occurred with the mixture of 10 parts of dinitrobenzol and 90 parts of nitrate.

At Firminy, where the same detonators were used, one miss-fire occurred in 34 shots with the mixture of 15 parts of cotton and 85 parts of nitrate of ammonia, and two mis-fires out of 21 shots with the dinitrobenzol and nitrate mixture.

At Blanzy, the explosion of the charge was not certain, even when detonators were used containing 30·86 and 46·30 grains of fulminate.

The results given by these two explosives need not be further discussed (*) as further experiments are to be made on cartridges manufactured at the Sevran-Livry Powder Mills with improvements suggested by the experiments, and a detailed account of which will be appended.

IV.—INSTANTANEOUS FUSE.

Instantaneous fuses are used in military operations, made of a more or less flexible tube of lead, tin, gutta-percha, &c., containing a high explosive such as gun-cotton, dynamite, &c. These fuses can transmit the explosion with remarkable speed. Mr. Berthelot, (†) from experiments made by the Explosives Substances Commission gives indeed a mean velocity of 17,000 feet per second as representing the speed with which the explosive wave is propagated through an instantaneous fuse of lead, of about ·04 inch internal diameter, filled with compressed gun-cotton.

These instantaneous fuses can be used when blasting in mines, by placing one of the ends into the cartridge and by covering the free end with a special detonator with two open ends ; the safety fuse being placed in the remaining opening.

The advantages are considerable : on one hand the stemming is made with greater safety ; and on the other, several cartridges can be fired with practically perfect simultaneousness. It is sufficient to attach to the principal fuze another piece of fuze, and to cut both so as to expose the explosive at the point of contact ; and to ensure their contact by wrapping the two fuses together with string.

About 220 yards of fuse, made of compressed gun-cotton in a tin tube, was sent to each colliery.

At Anzin, the contrivance was considered as hardly practicable, and without interest. At Firminy, opinion was a little less unfavourable. Mr. Mathet, at Blanzy, considered that the instantaneous fuses could be used advantageously when firing a number of simultaneous shots in the gobbing quarries. No reply was received from Ronchamp.

APPENDIX.

Since the report was sent to the printers, a communication (‡) has been received from Mr. Francois, of Anzin, giving an account of experiments made with the mixtures containing—(*a*) 10 parts of dinitrobenzol and 90 parts of nitrate of ammonia, and (*b*) 10 parts of octonitric cotton and 90 parts of nitrate of ammonia. These explosives were carefully manufactured at the Sevran-Livry Powder Mills, and sent for trial to several mine owners.

(*) See page 139.

(†) Comptes rendus de l'Academie des Sciences.—Vol. C., page 314 (Feb. 9, 1885).

(‡) See page 139.

The mixture containing dinitrobenzol will be shortly, it is said, placed on the market by the company owning the Favier patents.

The Explosives Administration announces that it has placed the cotton mixture on the market at the price of 1s. 5·2d. per pound.

Mr. Francois' note accompanies this report (*). He appears to be satisfied with the cartridges manufactured at Sevran-Livry Powder Mills.

Mr. Francois, in this note, treats of mixtures made of gelatinised nitro-glycerine and nitrate of ammonia, which are now currently used in the fiery Anzin collieries, where more than 20 tons have already been used. Three kinds are used, containing respectively 12, 20, and 30 parts of gelatinised nitro-glycerine; whose corresponding temperatures of detonation are, in round numbers, 2,732 degs., 2,912 degs., and 3,452 degs. F.; and their explosive forces have been estimated at 111, 118, and 122, that of no. 1 dynamite being 100. The two first mixtures, and especially the first, should be preferably used in the working of coal, and the third in working of stone.

(*) See page 136.

FIRST SERIES OF EXPERIMENTS.

I.—ANZIN COLLIERIES.

REPORT ON THE PRACTICAL EXPERIMENTS WITH THE EXPLOSIVES RECEIVED FROM THE SEVRAN-LIVRY POWDER MILLS.

Preliminary Experiments.—Before making the practical experiments requested by the Explosive Substances Commission, a few preliminary experiments were made to ascertain the explosive power of each of the three mixtures to be used. For this purpose 154·3 grains of each of the explosives was detonated in cubes of lead, 7·87 inches on each side. These cubes were fitted with a cylindrical hole, 0·47 inch diameter and 4·72 inches deep. The explosives were stemmed carefully into the hole, the detonator containing 23·15 grains of fulminate was placed on the top, and the hole was then filled up with very fine dry sand.

These experiments were several times repeated with the explosives, and with blasting-gelatine, and no. 1 dynamite, and from these repeated trials, the following table was prepared, shewing the power of these explosives, assuming that the volumes of the cavities produced are proportional to the power of the respective explosives, that of blasting-gelatine being taken at 100:

Nature of Explosive.	Length of Stemming.	Volume before Explosion.	Volume after Explosion.	Power of Explosive.
	Inches.	Cubic In.	Cubic In.	
Blasting-gelatine (Dynamite Company) ...	1·97	·824	22·534	100·00
10 dinitrobenzol, 90 nitrate of ammonia ..	1·18	·824	14·656	65·04
30 dynamite, 70 nitrate of ammonia ...	1·18	·824	12·449	55·25
15 gun-cotton, 85 nitrate of ammonia ...	0·39	·824	12·032	53·40
No. 1 dynamite (Dynamite Company) ...	1·97	·824	18·074	80·21

It was thought that the length of stemming above the charge of explosive might have a certain influence on the results. In the case of blasting-gelatine and no. 1 dynamite, with 1·97 inches of stemming, the excavation took the shape shewn in figure 1, whilst the other explosives, where there was less stemming, produced excavations similar to that shewn in figure 2. It is evident that the orifice of issue for the gases is not the same in the two cases, and it may be supposed, with the mixtures of the Commission, that the gases escaped before utilising all their explosive force in producing the excavation.

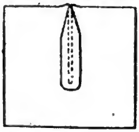


Figure 1.

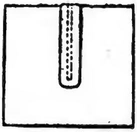


Figure 2.

Other experiments were then made by increasing the height of the leaden blocks so as to have 1·97 inches of stemming above the charge, all the other conditions being the same as in the preceding experiments.

The holes produced have been very similar to that of figure 1, but a marked increase of volume only occurred in the case of the mixture of gun-cotton and nitrate of ammonia :

NATURE OF EXPLOSIVE.	Length of Hole.	Length of Stemming.	Volume before Explosion.	Volume after Explosion.	Power of Explosive.
	Inches.	Inches.	Cubic In.	Cubic In.	
Blasting-gelatine (Dynamite Company)	4·72	1·97	·824	22·534	100·00
10 dinitrobenzol, 90 nitrate of ammonia...	5·51	1·97	·961	14·036	62·29
30 dynamite, 70 nitrate of ammonia	5·51	1·97	·961	12·358	54·84
15 gun-cotton, 85 nitrate of ammonia	6·30	1·97	1·098	16·019	71·09
No. 1 dynamite (Dynamite Company)	4·72	1·97	·824	18·075	80·21

Practical experiments were made by blasting in coal and stone, after these results were obtained.

Comparison with Blasting-Powder.

Experiments in Coal.—Miners do not use explosives in working coal in the Anzin collieries ; nevertheless, the two following series of experiments were made, which include most of the conditions found in practice. The experiments were made in the Renard Pit in the Henriette seam, which is 1 foot 11⅝ inches thick. In the first series, the shot holes *a b* (figure 3) were drilled 3 feet 11¼ inches deep

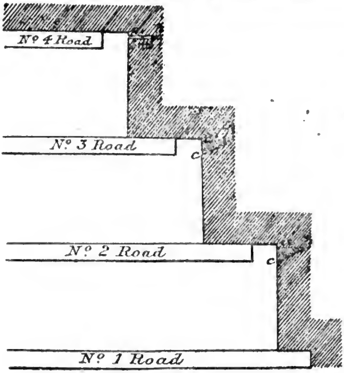


Figure 3.

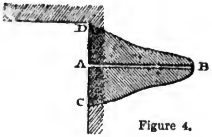


Figure 4.

in a direction at right angles to the working face. The shading shews the planes of cleavage. These shots should detach the prism of coal *a b c*. [Figure 4 shews the details, A B is a shot-hole in front of the gateway, and this shot should detach the prism of coal D B C.] Several absolutely similar shots were fired with compressed blasting-powder, and with the three explosives, and it was found that the following were the amounts required to produce equal effects :—

Compressed blasting-powder	5·0 ounces,
Dynamite and nitrate of ammonia ...	3·0 ,, ,
Dinitrobenzol and nitrate of ammonia ...	2·5 ,, ,
Gun-cotton and nitrate of ammonia ...	2·5 ,, ,

whence the comparative power of an equal weight of these explosives would be (that of blasting-powder being taken at 100) :—

Compressed blasting-powder	100,
Dynamite and nitrate of ammonia	166⅔,
Dinitrobenzol and nitrate of ammonia	200,
Gun-cotton and nitrate of ammonia	200.

In every case, whether the prism of coal was removed by hand, with blasting-powder, or with the other explosives, the coal is always very small.

In the second series of experiments, the holes were drilled, *a b* (figure 5), 3 feet 3¼ inches deep, for the purpose of detaching the block of coal *a b c d*. [Figure 6 shews the details, the shot E F being intended to dislodge the piece of coal E F G H.] All the shots were fired under the same conditions, the blasting-powder also being ignited with a detonator containing 23·15 grains of fulminate.

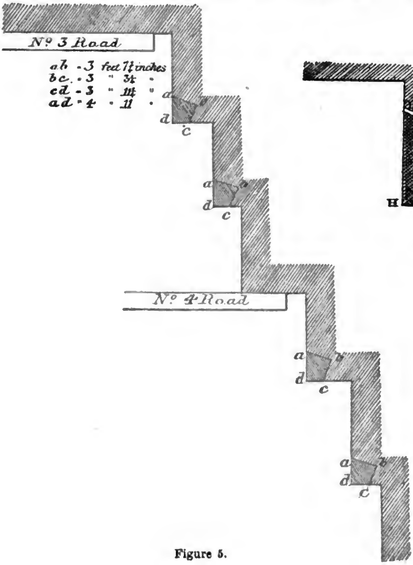


Figure 5.

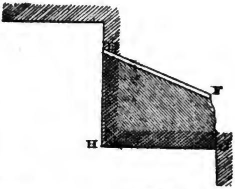


Figure 6.

From a comparison of the results obtained, the relative power of an equal weight of the explosives would be (that of blasting-powder being taken at 100) :—

Compressed blasting-powder	100,
Dynamite and nitrate of ammonia	166⅔,
Dinitrobenzol and nitrate of ammonia...	166⅔,
Gun-cotton and nitrate of ammonia	200.

The mixture of dinitrobenzol and nitrate of ammonia produced the same proportion of round coal as blasting-powder. The other two explosives produced about 12 per cent. more small coal. In one of the shots, charged with dinitrobenzol and nitrate of ammonia, the detonator exploded without detonating the explosive.

Comparison with Blasting-Gelatine.

Experiments in Stone.—It was considered most important to see how these explosives acted in making roadways in thin seams in fiery pits.

Dynamite is used for this work at the Anzin collieries, A hole is drilled 3 feet 11¼ inches deep in the thill of the roadways, as shewn in figures 7 and 8,

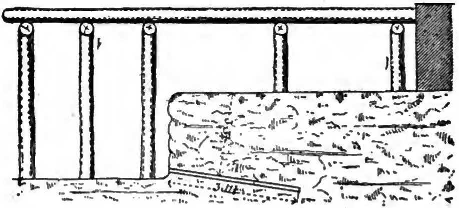


Figure 7.

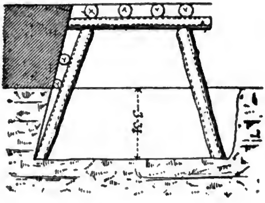


Figure 8.

and 9 and 10, and this shot usually lifts 3 feet 4 inches in thickness of stone, in the case of a working seam 1 foot 11½ inches thick.

Several shots were fired under the same conditions, with blasting-gelatine, and with the three experimental explosives, and the following are the ascertained values of the explosive force for equal weights, that of blasting-gelatine being taken at 100 :

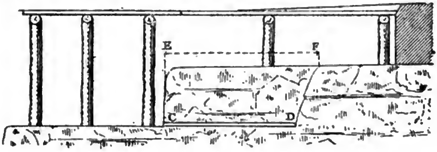


Figure 9.

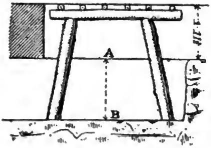


Figure 10.

Blasting-gelatine (Dynamite Company)	100,
Dinitrobenzol and nitrate of ammonia	80,
Dynamite and nitrate of ammonia	75,
Gun-cotton and nitrate of ammonia	72.

These explosives reduced the stone to smaller pieces than blasting-gelatine, which is desirable.

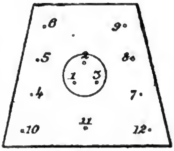


Figure 11.

The explosives were also tried in drifts driven by machine drills, (*) and excellent results were obtained, comparable, as regards explosive power, to those obtained in the enlargement of roads, so long as the charge did not exceed 6,173 grains.

This fact can be explained in the following manner :—a shot charged, for instance, with the least voluminous mixture (dinitrobenzol and nitrate of ammonia) occupies 2 feet 3·56 inches of the length of the hole, whilst the corresponding charge of blasting-gelatine only occupies 11·81 inches. In hard stone, where heavy charges are required, it is evident that the charge which occupies the least length of hole will shatter the stone more thoroughly than a charge of equal power of another explosive, which would occupy a greater length of hole. This has been frequently ascertained, shots charged with blasting-gelatine shattered the stone back to the end of the hole, while equally powerful charges of the Commission's explosives only shattered the stone for 8 or 12 inches at the outer end of the hole, even when the charge exceeded 5,400 or 6,200 grains.

[(*) The position and order of firing of the various shots is shewn in figure 11, blasting-gelatine was always used in the case of nos. 1, 2, and 3 shots, and the mixed explosives were used in nos. 4, 5, 6, 7, 8, and 9 holes. The holes were 3 feet 11½ inches long. The beds of schist were horizontal, with about 1 foot 8 inches of post near the roof.]

Lastly, each of the three explosives were fired in holes tamped with water. A cartridge of blasting-gelatine contained the detonator. The effects produced were similar to those obtained with ordinary stemming.

Speaking generally, the fumes are less obnoxious than those produced by blasting-gelatine.

Conclusions.

Briefly, the experiments have been very satisfactory. The mixture of 10 parts of dinitrobenzol and 90 parts of nitrate of ammonia, gave the best result for heavily charged shots, which may be easily explained by accepting the last-named theory, and remembering that this explosive is the least voluminous. The mixture of gun-cotton and nitrate of ammonia, which gave the best results in the two trials in lead, resumes its superiority in lightly charged shots, and this was confirmed by the second series of experiments in coal, where all the shots were lightly charged. This mixture is the most voluminous one.

For shots requiring charges heavier than 6,173 grains, it will always be advisable to use blasting-gelatine, whose use is always preferable in stone drifts and staples driven by machine drills. The new explosives advantageously replace blasting-gelatine, no. 1 dynamite, and blasting-powder, for coal-getting, and for stone work, especially in the enlargement of roads in fiery mines.

The 771·6 grain cartridge is 5·91 inches long with the mixture of gun-cotton and nitrate of ammonia, 4·92 inches with the mixture of dynamite and nitrate of ammonia, 4·33 inches long with the mixture of dinitrobenzol and nitrate of ammonia, whilst the 1,543·2 grains cartridges of the various kinds of dynamite are only 4·72 inches long.

Undoubtedly the results given by these explosives could be improved, if they were compressed into smaller volumes.

Two-thirds should be supplied in 1,543·2 grains cartridges of 1·18 inches diameter, and the remainder in 771·6 grains cartridges.

At the end of a month, the explosives in the cartridges were still very dry, and in good condition.

Instantaneous Fuse.

The instantaneous fuse weighs 470 grains per running foot, and contains about 154·47 grains of gun-cotton. On explosion, the tin tube is shattered to fragments. It should only be used in the simultaneous firing of several shots. A long time and much skill is required to make the junctions on the fuse which is attached to the ordinary safety fuse, and in the experiments which have been made there has always been at the least one missed shot to four shots properly fired.

With electricity, several shots could be fired simultaneously in a more rapid and economical way.

12th October, 1888.

[NOTE.—The details of the experiments have not been translated. They will be found in the *Annales des Mines*, 1889, Vol. 16, pages 30-37.]

II.—BLANZY COLLIERIES.

TRIALS OF THE NEW EXPLOSIVES FROM THE SEVRAN-LIVRY POWDER MILLS.

Herewith are forwarded the results (*) obtained with the three kinds of explosives, of which three sample cases of 100 cartridges each were forwarded. These results are divided into three tables under the headings of :—Explosives no. 1, no. 2, and no. 3, which summarise the number of shots, the charge, and the mass detached in tubs containing 1,234 pounds.

In addition to the tables, there is a detailed statement giving, for each shot of no. 1 explosive (which appears to be the only practical one), all the details relative to the firing of each shot, with sketches of the working places, the effects produced, volumes detached, the effects of the fumes on the workmen, &c., &c.

The difficulties which have been experienced in detonating no. 2 and no. 3 explosives, and particularly the latter, render them certainly of little practical use.

Instantaneous Fuse.—Trials of instantaneous fuse for the simultaneous firing of several shots were made ; but the unusual consumption of strong detonators, and the care which the wrappings require when ordinary detonators open at one end are used, have led to the interruption of these trials, and to an order being sent to the Gaupillat Company for a supply of *coupling* detonators, charged with 30·86 grains of fulminate.

These experiments will be resumed as soon as these detonators are supplied

Only two experiments have been made with the following results :

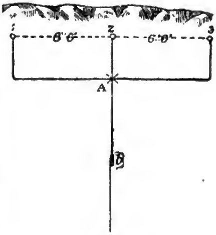


Figure 12.

In an open quarry three shot holes were drilled 31·50 to 35·43 inches deep, the distances between each hole being about 6 feet 6 inches. The fuse was arranged as shewn in figure 12. One of the ends leading from the charge (1,543·2 grains) of gelatine in no. 1 hole, containing a strong detonator, extended along the ground and entered no. 3 hole containing a charge and detonator. Another end of fuse with charge and detonator was placed in no. 2 hole, and was joined to the first by simple binding at A, prepared by exposing the substance in the two fuses and then uniting the bared surfaces with strong string. The end *b* was fitted with a strong detonator which was united to another, containing the end of the ordinary fuse to which the light was applied.

[(*) The details of the experiments have not been translated. They will be found in the *Annales des Mines*, 1889, Vol. 16, pp. 37-47.

The following remarks may, however, be introduced.

No. 1 Explosive, containing 30 parts of Dynamite and 70 parts of Nitrate of Ammonia.—This explosive was ignited completely with Abegg electrical detonators (triple) containing 8·33 grains of fulminate. No flame was observed.

No. 2 Explosive, containing 15 parts of Gun-cotton and 85 parts of Nitrate of Ammonia.—This explosive was ignited with fuse and detonators containing 30·86 grains of fulminate. The complete combustion of the charge has not been always produced with these detonators, in two cases the explosive remained intact. No flames were observed.

No. 3 Explosive, containing 10 parts of Dinitrobenzol and 90 parts of Nitrate of Ammonia.—This explosive was only ignited by placing the detonator in the midst of the charge, but there have been charges which were not ignited. In the last two experiments, with 46·30 grains detonators, some of the explosive was left intact in the bottom of the hole. Flame was not observed.]

The result was satisfactory, the instantaneousness perfect, and the displacement of stone considerable. The length of fuse employed was 29½ feet.

Five shots, 1, 2, 3, 4, and 5 (figure 13), in the same quarry had been drilled 3 feet 7·31 inches deep on the side of a ledge. They were capped, charged, and stemmed as before; but the charge of gelatine was 4,629·7 grains for each shot. There were three connections from fuse to fuse, and one at A from detonator to detonator.

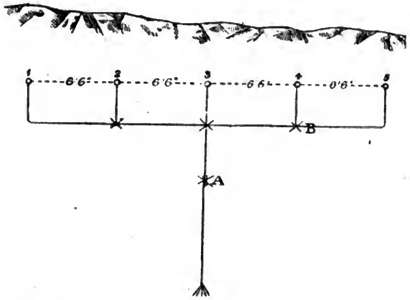


Figure 13.

The shots 1, 2, 3, and 5 were fired simultaneously, producing one and the same detonation; but the fourth shot was not fired, the fuse being broken at the connection B. This same fuse was tried twice afterwards without success; a third attempt was more successful, and the shot fired.

The cause of this failure was doubtless due to the fuse being too large in diameter for the detonators, and it may be that the fuse was not in perfect contact with the fulminate.

As soon as the *coupling* detonators are received, these experiments will be resumed.

November 7, 1888. A. Mathet.

The results obtained with the instantaneous fuse have now been completed.

Fifty-eight shot-holes, about 3 feet 4 inches deep, and from 3 feet 4 inches to 3 feet 8 inches apart, were prepared on the side of a bench in the gobbing quarries. Each of these holes was charged with a gelatine cartridge of 1,543·2 grains, capped, with a length of fuse from 4 feet 3 inches to 4 feet 7 inches inserted into a cap of 30·86 grains of fulminate.

Each of these pieces corresponding to each hole, was united to the principal fuse laid on the ground, close to the shot holes, by means of a string which bound together the points of contact, previously stripped down to the explosive substance.

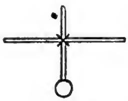


Figure 14.

The three last shots 56, 57, and 58 had been connected to the principal fuse by a crossed binding, as shewn in figure 14; whilst with all the other shots the ligature was tied tangentially, as shewn in figure 15, which certainly is the best.

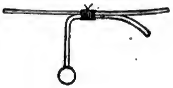


Figure 15.

On the firing of this series of 58 shots, only one violent detonation was heard, the first 55 shots did good work; but the three last, which had been connected by the crossed binding, did not explode. When retied to the principal fuse by a tangential ligature they fired immediately.

The length of fuse used in this experiment was 197 feet for the main fuse, and 247 feet for the branch fuses to the holes. This experiment seems conclusive, and shews that every time a great number of shots are to be simultaneously fired, as may occur in a quarry or even in sinking shafts, the use of instantaneous fuse will advantageously replace the use of electricity.

November 24, 1883. A. MATHET.

III.—FIRMINY COLLIERIES.

REPORT ON THE PRACTICAL EXPERIMENTS MADE AT THE FIRMINY COLLIERIES, AT THE REQUEST OF THE EXPLOSIVE SUBSTANCES COMMISSION.

The various mixtures were tried as follows:—

No. 1.—30 parts of dynamite and 70 parts of nitrate of ammonia,
No. 2.—15 parts of octonitric gun-cotton and 85 parts of nitrate of ammonia,
No. 3.—10 parts of dinitrobenzol and 90 parts of nitrate of ammonia.

The results of the experiment are summarised in the following tables (*):—

No. 1, in coal, table A; No. 1, in stone, table A′;
No. 2, in coal, table B; No. 2, in stone, table B′;
No. 3, in coal, table C; No. 3, in stone, table C′.

The coal-getting experiments were made in a rather hard seam of coal, whose thickness is about 20 feet, and the inclination 25 degs., and which is worked in horizontal lifts. The levels, on the thill, and the cross levels, extending from thill to roof, are 10 feet wide and 8½ feet high. The lifts, which extend from thill to roof, are 33 to 40 feet wide.

The stone trials were made in compact schist, and in post, in driving the cross drifts, or in taking down the roof of a thin seam.

These experiments will now be described under different heads:—(1) The difficulties or disadvantages of the use of the new explosives; (2) their useful effect in coal-getting; (3) the condition of the detached coal; and (4) the economic results.

(1). *Difficulties or Disadvantages.*

Whatever explosive is used, it is important that no empty space be left between the charge and the sides of the shot-hole. With dynamite this condition is easily realised: the cartridges are cut and the charge is forced to the end of the hole with the stemmer, only reserving a portion of the cartridge of length strictly necessary for the insertion of the detonator. With loose blasting-powder, the workman puts the charge into a paper cartridge suitable to the diameter of the hole drilled. The new explosives are pulverised and protected against damp by a double wrapping of paraffined paper. The cartridges cannot be divided into pieces, because the loose substance spills out. No incisions should be made in the paper. The external wrapper should only be removed, and the cartridges thoroughly stemmed in the bottom of the hole; but the filling up of any vacant space is not effected, owing to the resistance of the paraffined paper. This inconvenience may be diminished, if cartridges of various diameters are provided.

The detonator should be placed in one whole cartridge, which must not be crushed. To diminish as much as possible the length of the space which perforce remains around this last cartridge, it would be desirable to have special cartridges of the same length as the detonators.

(*) The details of the experiments have not been translated. They will be found in the *Annales des Mines*, 1889, Vol. 16, pp. 54-59.]

As the cartridges can not be divided, it will be necessary to have at hand cartridges of graduated lengths so as to vary at will the charge in blasting. With dynamite and blasting-powder this difficulty does not exist.

It requires about five minutes more to charge a hole with the new explosives than with blasting-powder or dynamite.

The nitrate of ammonia explosives yield no fumes. A very disagreeable smell is experienced when these cartridges are used; but this bad odour may be avoided if, before charging, the outside wrapper is removed, and the paraffin adhering to the inner wrapper is scraped away.

With the no. 2 explosive, one missed shot occurred out of 34 shots; the three cartridges in it burnt without detonating, although great care had been taken that the fuse *never penetrated into the cartridge.*

With the no. 3 explosive two missed shots occurred out of 21 fired; in these two shots, the detonator only had detonated, and the substance was recovered in rather hard yellowish lumps. Perhaps it had been already altered before use.

(2). *Useful Effect.*

In getting coal, each shot usually consisted of 5,092·7 grains of loose blasting-powder or 1,311·7 grains of blasting-gelatine. It was found that the same effective result was obtained with 2,314·8 grains (3 cartridges) of the no. 1 explosive. Explosive no. 2 was a little less powerful, and no. 3 was still less powerful.

Occasionally, when the "kirving" was insufficient or the coal a little hard, instead of breaking down the coal over the "kirving," only a conical piece of coal was thrown from the face.

In stone work, one cartridge of 771·6 grains of the explosives nos. 1, 2, or 3 appears equivalent to a triple charge of blasting-powder.

(3). *Condition of the Detached Coal.*

The state of division of the detached coal was generally the same as with dynamite, and almost the same as with blasting-powder. With the nitrate of ammonia explosives, as with dynamite, there are always 8 or 10 lbs. of powdered coal around the charge; that is the only difference found as compared with the effects of blasting-powder.

(4). *Economic Results.*

In coal work, the cost of one ordinary shot is :—

	Grains.	Per pound.			
Blasting-powder ...	5,092·7 at	10·12d.	... ...		= 7·36d.
Blasting-gelatine ...	1,311·7 at	2s. 4·01d.	...	+ ·50d.(*) ...	= 5·75d.
Explosive no. 1 ...	2,314·8 at	x	...	+ ·50d.(*) ...	= ?
,, ,, 2 ...	2,314·8 at	x	...	+ 1·00d.(†) ...	= ?
,, ,, 3 ...	2,314·8 at	x	...	+ 1·00d.(†) ...	= ?

The time required in charging should also be reckoned; as previously remarked, it takes about five minutes more with the new explosives than with powder or dynamite.

Instantaneous Fuse.

The instantaneous fuse from the Sevran-Livry Powder Mills has also been tried. It allows several shots to be fired perfectly simultaneously. It was found that for the transmission of explosion, it was necessary to fix a plugged detonator at the beginning of each branch. It was also found that it was not sufficient to strip the covering and place the gun-cotton in contact.

This fuse would be of service in fiery mines by allowing several shots to be fired at a time, but the regulations require the use of one fuse to each shot.

H. VOISIN.

[NOTE—The details of the experiments have not been translated. They will be found in the *Annales des Mines*, 1889, Vol. 16, pp. 54-59].

[(*) Ordinary detonator]. [(†) Plugged detonator.]

IV.—RONCHAMP COLLIERIES.

EXPERIMENTS WITH THE EXPLOSIVES SENT FROM THE SEVRAN-LIVRY POWDER MILLS.

The experiments were made in a stone drift in the south district of the Magny Pit. They were made for the purpose of comparing these explosives with no. 1 dynamite.

Speculative experiments were inadmissible, as there was only a rather small quantity of each of these explosives (about 11 pounds). Moreover, it was thought desirable not to make any change in the ordinary method of working the stone drifts; depth, position, number of shot-holes, all remained under the same conditions.

As regards the charge, the weight of no. 1 dynamite usually employed was replaced by an equal weight of the new explosives.

The stemming was made as usual, with from two to three inches of clay; lastly, as regards detonators, use was made of the so-called *extra strong* detonators of the Dynamite Company.

The face of the working place was entirely in compact schists; the inclination of the strata being only a few units per cent., and all the experiments having been made almost simultaneously, it may be assumed that as regards facility of detachment, the place remained constantly under the same conditions.

On an examination of the summarised experiments, it is evident that, as regards blasting-power, the explosives may be classed in the following manner:—

Dynamite no. 1	100,
No. 1 (30 parts of dynamite and 70 parts of nitrate of ammonia)	97,
No. 2 (10 parts of dinitrobenzol and 90 parts of nitrate of ammonia)	95,
No. 3 (15 parts of gun-cotton and 85 parts of nitrate of ammonia)	79.

Nos. 1 and 2 explosives appear to differ very little from dynamite no. 1. Nevertheless, it must be remembered that the blasting was effected under especially favourable conditions for two reasons:—(1) the presence of two slips in the face; and (2) the softness of the stone.

Experiments made in harder stone would certainly be more conclusive; the explosives would remain ranked in the same order, but it is probable that each of them would possess a materially lower co-efficient.

In conclusion, it may be noted that the fumes of these explosives cause a rather severe coughing, and appear (especially those of no. 3) to be more painful to respire than those of no. 1 dynamite.

NOTE.—As regards ignition, the so-called safety fuse was used.

Ronchamp, December 3, 1888.

[NOTE.—The details of the experiments have not been translated. They will be found in the *Annales des Mines*, 1889, Vol. 16, pp. 62-65.]

SECOND SERIES OF EXPERIMENTS.

I.—ANZIN COLLIERIES.

REPORT ON THE TRIALS MADE WITH EXPLOSIVE MIXTURES SENT FROM THE SEVRAN-LIVRY POWDER MILLS.

1. Mixture of 20 parts of nitrate of cupro-ammonia and 80 parts of nitrate of ammonia.
2. Mixture of 70 parts of nitrate of cupro-ammonia and 30 parts of nitrate of ammonia.
3. Mixture of 5 parts of naphthalene and 95 parts of nitrate of ammonia.
4. Mixture of 20 parts of no. 1 dynamite and 80 parts of nitrate of ammonia.

Before making the practical experiments, some preliminary trials were made so as to ascertain the explosive power of each of the four mixtures to be tried. These experiments consisted in the explosion of 154·3 grains of each substance in leaden cubes of 7·87 inches on the side. The cubes of lead were pierced, following the vertical axis by a cylindrical hole 0·47 inches in diameter, and of variable length so as to ensure 1·97 inches of stemming above 154·3 grains of explosive. The mixture to be tried was carefully stemmed into the hole, a detonator was placed above containing 23·15 grains of fulminate of mercury; and the hole was then filled up with very fine dry sand. These experiments, several times repeated, gave every time the same result for the same mixture, which shews that these experiments are perfectly comparable for the same explosive substance; but for compositions of different kinds, each having a particular mode of decomposition, the results are only comparable with each other with a certain degree of approximation.

At the end of these trials, the following table was drawn up, shewing the explosive powers of each of these mixtures, assuming that the volumes of the cavities produced are proportional to the powers of the said explosives; the explosive force of blasting-gelatine being taken at 100.

Nature of Explosives.	Length of Stemming.	Length of Hole.	Volume before Explosion.	Volume after Explosion.	Power of Explosive.
	Inches.	Inches.	Cub. Ins.	Cub. Ins.	
Blasting-gelatine	1·97	4·72	·824	22·534	100·00
No. 1 { 20 parts of nitr. of cup.-amm., and 80 parts of nitrate of ammonia }	1·97	5·51	·961	9·916	44·01
No. 2 { 70 parts of nitr. of cup.-amm., and 30 parts of nitrate of ammonia }	1·97	5·51	·961	13·243	58·77
No. 3 { 5 parts of naphthalene, and 95 parts of nitrate of ammonia... }	1·97	5·12	·892	15·134	67·16
No. 4 { 20 parts of no. 1 dynamite, and 80 parts of nitrate of ammonia }	1·97	5·91	1·029	11·686	51·86

The practical experiments consisted in firing shots for the enlargement of roads in thin seams. The charges of explosives varied from 1,543·2 grains to 9,259·4 grains. The charges used were compared with those which would have been used of blasting-gelatine, and it was considered that with the same weight the explosive power of the mixtures tested is so much per cent. of that of blasting-gelatine.

Some of these mixtures detonated very badly; several times after lighting the fuse, detonation was heard, but the shot was not blown out, and the stone was undisturbed. The explosion shews that the fulminate had detonated and probably with it a portion of the mixture. The unramming of shots being prohibited, the quantity of explosive which had detonated along with the cap could not be ascertained. In the report and in the detailed list, this case is indicated under the name of partial detonation without blowing out.

At other times detonation was heard, the stone remained intact, but the shot was blown out; a portion of the mixture remaining undetonated at the end of the hole. This special case is indicated under the name of partial detonation with blowing out.

With mixtures which detonate badly, it was thought that the folds of paper which are found at the ends of the cartridge might be an obstacle to the propagation of the explosive wave; sometimes, indeed, this thickness of paper reached 0·24 inch at one end, and very frequently this paper was removed so that the explosive formed a continuous cylinder in the shot-hole. This method of charging is indicated by saying that the cartridges were unsealed.

The following are the results of these experiments:—

(1). *Mixture of 20 parts of Nitrate of Cupro-Ammonia and 80 parts of Nitrate of Ammonia.*

In two shots, whose detonation was provoked by a detonator containing 23·15 grains of fulminate of mercury, there occurred each time only a partial detonation without blowing out. The cartridges were unsealed.

In two other shots, whose detonation was provoked in each case by two detonators placed side by side, together containing 46·30 grains of fulminate, one partial detonation occurred without blowing out, and one partial detonation with blowing out. The cartridges were also unsealed.

This mixture appeared to detonate completely when a cartridge of blasting-gelatine or no. 1 dynamite is used as a priming cartridge with a detonator containing 11·57 grains of fulminate of mercury.

It was found by firing several shots under these conditions, that the explosive force of this mixture was 54 per cent. of that of blasting-gelatine.

(2). *Mixture composed of 70 parts of Nitrate of Cupro-Ammonia and 30 parts of Nitrate of Ammonia.*

In three shots, whose detonation was provoked by a detonator containing 23·15 grains of fulminate of mercury, two shots fired well, and the third was partially detonated without blowing out.

In four shots, whose detonation was each time provoked by two detonators containing 46·30 grains of fulminate of mercury, three shots fired well, but the fourth partially detonated without blowing out.

From the five well-fired shots, it appears that the explosive force of the mixture is 57·6 per cent. of that of blasting-gelatine.

This mixture appeared to be very completely detonated every time, by the use of a cartridge of blasting-gelatine as a priming cartridge.

In the above seven experiments, the cartridges were unsealed.

After the explosion, the fumes were very dense and irritated the mucous membranes of the eyes and nose.

Nitrate of cupro-ammonia contains 24·85 per cent. of copper, and as the mixture includes 70 per cent. of this nitrate, it must contain 17·4 per cent. of copper. After explosion, this copper is probably suspended in the atmosphere in the state of dust oxide of copper (the decomposition yields an excess of oxygen), which dust will be breathed by the workmen, and might cause injurious results.

(3). *Mixture composed of 5 parts of Naphthalene and 95 parts of Nitrate of Ammonia.*

This mixture detonated very badly.

The cartridges have always been unsealed.

In five shots, whose detonation was effected by a detonator containing 23·15 grains of fulminate of mercury, two shots have given partial detonations without blowing out, and the three other shots were partial detonations with blowing out.

In two other shots, whose detonation was provoked each time by three detonators, together containing 69·45 grains of fulminate of mercury, only partial detonations without blowing out occurred.

In one of these shots, 6,172·9 grains of the mixture were left at the bottom of the hole (out of 9,259·4 grains of the charge), two cartridges of blasting-gelatine were placed on the top and one detonator of 11·57 grains; the shot fired well; nevertheless when clearing it away, pieces of the mixture were found which had not detonated. The largest of these fragments weighed 123·46 grains, and the mixture was melted. This fact emphasised the low aptness of detonation of this explosive.

By placing 1,543·2 grains or 3,086·5 grains of this mixture with charges of at least 4,629·7 grains of blasting-gelatine, complete detonation was obtained, and its explosive force was estimated as 72 per cent. of that of blasting-gelatine.

(4). *Mixture composed of 20 parts of No. 1 Dynamite and 80 parts of Nitrate of Ammonia.*

It was ascertained that the mixture in several cartridges was very badly made. The grains of nitrate of ammonia were not more than ·04 inch, but the grains of no. 1 dynamite were as large as 0·28 inch.

This mixture detonated freely with detonators containing 23·15 grains of fulminate of mercury, and also with detonators containing 11·57 grains.

The explosive force, for shots with less than 7,716·2 grains, is 64·1 per cent. of that of blasting-gelatine.

This mixture gives off less fumes than the different dynamites.

General Observations.

Of the four explosives tested, two are wanting in facility of detonation, and ought to be set aside for that reason. These two mixtures are: (1) that composed of 20 parts of nitrate of cupro-ammonia and 80 parts of nitrate of ammonia, and (2) the mixture of 5 parts of naphthalene and 95 parts of nitrate of ammonia.

The third mixture composed of 70 parts of nitrate of cupro-ammonia and 30 parts of nitrate of ammonia was only detonated completely five times out of seven; it is also deficient in facility of detonation, and further there is reason to consider whether it should not be rejected on account of the large proportion of copper it contains, and the noxious influence which these dusts may exercise on the bodies of the workmen.

The fourth mixture composed of 20 parts of no. 1 dynamite and 80 parts of nitrate of ammonia is the only one which is really practicable.

These explosives were supplied in cartridges of 771·6 grains and 1,543·2 grains. The 771·6 grains cartridges were 1·18 inches diameter, and averaged 4·53 inches long; those of 1,543·2 grains were 1·30 inches diameter, and averaged 7·09 inches long, which saved a length of 1·97 inches when 1,543·2 grains were used, and, by using 1,543·2 grains cartridges, the density of charging was increased $\frac{1\cdot 97}{2 \times 4\cdot 53} = 21$ per cent. above that obtained by using cartridges of 771·6 grains. About 90 per cent. of the supply should be in the form of 1,543·2 grains cartridges, and only 10 per cent. of 771·6 grains. They should all be 1·30 inches diameter.

Conclusions.

Three of the explosives tried some months ago remain available, viz.:—

1. 10 parts of dinitrobenzol and 90 parts of nitrate of ammonia;
2. 15 parts of octonitric gun-cotton and 85 parts of nitrate of ammonia;
3. 30 parts of no. 1 dynamite and 70 parts of nitrate of ammonia;

and one of the latest mixtures, that which consists of:—

4. 20 parts of no. 1 dynamite and 80 parts of nitrate of ammonia.

According to the experiments of the Explosive Substances Commission, the last mixture gives greater safety than the former, and as it has been proved really practicable, there is justification for its trial in a pit for several months and on a considerable scale.

The mixtures of dinitrobenzol and nitrate of ammonia, and of gun-cotton with nitrate of ammonia, have also been recognised as very practicable, but they were sometimes found defective in the experiments of the Explosive Substances Commission.

It should be remembered that these explosives cannot be used to advantage with charges greater than 7,716·2 grains, and that blasting-gelatine and no. 1 dynamite will always be used for work requiring the use of heavy charges, such as stone drifts driven by the machine drills, sinking of shafts, &c., &c.

The new explosives should be reserved for the ordinary workings, such as enlarging roads in thin seams, driving of inclined planes, and coal-getting in mines where this work is affected with powder. Such work is most dangerous, owing to the presence of fire-damp.

February 15, 1889.

[NOTE.—The details of the experiments have not been translated. They will be found in the *Annales des Mines*, 1889, Vol. 16, pp. 71-75].

II.—FIRMINY COLLIERIES.

REPORT ON THE SECOND SERIES OF PRACTICAL TRIALS MADE IN THE FIRMINY COLLIERIES, AT THE REQUEST OF THE EXPLOSIVE SUBSTANCES COMMISSION.

The following explosive mixtures were tried :—

No. 1, 20 parts of nitrate of cupro-ammonia and 80 parts of nitrate of ammonia ;
No. 2, 70 parts of nitrate of cupro-ammonia and 30 parts of nitrate of ammonia ;
No. 3, 5 parts of naphthalene and 95 parts of nitrate of ammonia ;
No. 4, 20 parts of dynamite and 80 parts of nitrate of ammonia.

The trials were made in the same workings, and under the same conditions as those described in the report of November 29, 1888.

The results are stated in the appended tables. (*)

The difficulties and disadvantages are the same as those indicated for the explosives previously tried. The workmen, moreover, complained of the bad odours which remained for some time after firing; sometimes they have even had pains in the head and eyes.

Nos. 1 and 3 explosives could not be detonated with plugged caps containing 23·15 grains of fulminate. In the first experiments, the cartridges were well rammed; in the latter they were only lightly rammed; in every case the hole was well stemmed; and the result has always been negative.

With no. 2 explosive, when using the 771·6 grains cartridges, the detonator cartridge alone detonated, and the others were found intact.

In working coal, 3,086·5 grains of the explosives nos. 2 and 4 produced nearly the same result as 5,092·7 grains of loose blasting-powder, or 1,311·7 grains of blasting-gelatine.

The condition of the detached coal is generally the same as with dynamite, and nearly the same as with blasting-powder.

March 9, 1889. H. VOISIN.

III.—BLANZY COLLIERIES.

REPORT ON THE TRIALS OF THE EXPLOSIVE MIXTURES FROM THE SEVRAN-LIVRY POWDER MILLS.

No. 1 Explosive, 20 parts of Dynamite and 80 parts of Nitrate of Ammonia. (†)

The shots in coal, charged with the new powder, worked very well, when the charge was increased in the proportion of 2 to 3 of the usual charge of blasting-gelatine. The fumes are rather disagreeable ; no observations have been made as to the presence of flame.

New Mixtures.

No. 2 explosive, nitrate of cupro-ammonia 70 parts and nitrate of ammonia 30 parts.

No. 3 explosive, naphthalene 5 parts and nitrate of ammonia 95 parts.

No. 4 explosive, nitrate of cupro-ammonia 20 parts and nitrate of ammonia 80 parts.

[(*) The details of the experiments have not been translated. They will be found in the *Annales des Mines*, 1889, Vol. 16, pp. 78-83.]

[(†) The details of the experiments have not been translated. They will be found in the *Annales des Mines*, 1889, Vol. 16, pp. 84-86.]

It may be concluded from the experiments with the different powders :—

1. That nos. 1 and 2 may advantageously replace compressed powder for working stone or coal ; and that they are inferior to dynamite or blasting-gelatine ;

2. That, in the workings, the fumes derived from the explosion are more disagreeable than those from dynamite or blasting-gelatine ;

3. That no. 3, and especially no. 4 explosive, are very difficult to detonate, even with charges of fulminate of 30·86 grains and upwards ; and that, for this reason, and owing to the disadvantages which result during their ordinary use, and the least of which would be the loss of the charged and miss-fired shots, they cannot be generally used in mines.

There have been no observations made as to the flames produced, and consequently as to their action in an air charged with fire-damp.

March 28, 1889. A. MATHET.

IV.—RONCHAMP COLLIERIES.

EXPERIMENTS ON THE DUAL EXPLOSIVES SENT FROM THE SEVRAN-LIVRY POWDER MILLS.

The conditions were made absolutely similar to those of the experiments of December, 1888, in order to try the practical working of these new explosives. The trials were made in a stone drift going south from the Magny pit. It was being driven in fragile stone, fissured, and consequently easy to break down during December, 1888; at this time the drift was in conglomerate. It may be said, as regards blasting, that it was under particularly unfavourable and almost exceptional conditions. Indeed, there is no stone in Ronchamp more difficult to blast ; the bastard posts are certainly harder to drill, but the shots work better.

The mixture of 20 parts of dynamite and 80 parts of nitrate of ammonia was the only one which gave any result. But the experiments shew that the useful effect of this mixture is less than half that of no. 1 dynamite.

All the shots were very carefully stemmed with clay.

Safety fuse and the so-called extra strong caps of the Dynamite Company were used for igniting the shots.

The workmen found the fumes of these explosives very troublesome to breathe ; especially the mixtures of nitrate of cupro-ammonia and nitrate of ammonia.

March 30, 1889. T. GRUNER.

[NOTE.—The details of the experiments have not been translated. They will be found in the *Annales des Mines*, 1889, Vol. 16, pp. 88-89].

SUPPLEMENTARY DOCUMENTS.

ANZIN COLLIERIES.

I.—ON EXPLOSIVES USED AT THE ANZIN COLLIERIES.

Historical.

In consequence of Mr. Mallard's reports on behalf of the Explosive Substances Commission, and of the experiments made on some explosives sent by the Commission, the Anzin Collieries Company commenced to use the new explosives in their gassy workings, always observing the same measures of precaution in firing shots as formerly.

The Anzin Collieries Company applied to the Dynamite Company for supplies of mixtures of dynamite or gelatinised nitro-glycerine and nitrate of ammonia, prior to the time when the Government Powder Mills were able to supply the new explosives.

First Explosive Used.

The first order was for half a ton of a mixture of 20 parts of dynamite and 80 parts of nitrate of ammonia, which affords high guarantees of safety; its temperature of detonation being only 2,732 degs. F. This mixture was supplied in cartridges weighing 1,419·8 grains, and being 1·30 inches diameter and 4·53 inches long. It was enclosed in a double envelope of rather thin and impermeable paper. The cartridges were arranged in 4·4 pounds pasteboard boxes, and hermetically sealed. These boxes were then placed in the usual way inside wooden chests.

This explosive detonated very freely with plugged detonators containing 11·57 grains of fulminate of mercury. Its actual explosive power has been recognised as equal to 91 per cent., that of no. 1 dynamite being 100. The density was only 0·936. This explosive contained 20 per cent. of no. 1 dynamite consisting of 75 per cent. of nitro-glycerine, and consequently a certain quantity of silica or inert matter which it appeared desirable to avoid.

Second Explosive Used.

In consequence of the indications given in the second report of the Commission (page 88), and on the advice of Mr. Mallard, it was sought to suppress the 5 per cent. of inert matter and replace the no. 1 dynamite by nitro-glycerine slightly gelatinised by means of an addition of 2 to 3 per cent. of octonitric cotton. This blasting-gelatine is very plastic; its density is 1·43; it readily fills the empty spaces between the grains of nitrate of ammonia, and, consequently, materially increases the density of the mixture, which is very important as regards the practical explosive power.

The curves (figure 16) shew the temperature of detonation and the force of the explosive for different mixtures of these two substances. The abscissæ shew the proportions of nitrate of ammonia and the ordinates the corresponding temperatures and explosive forces.

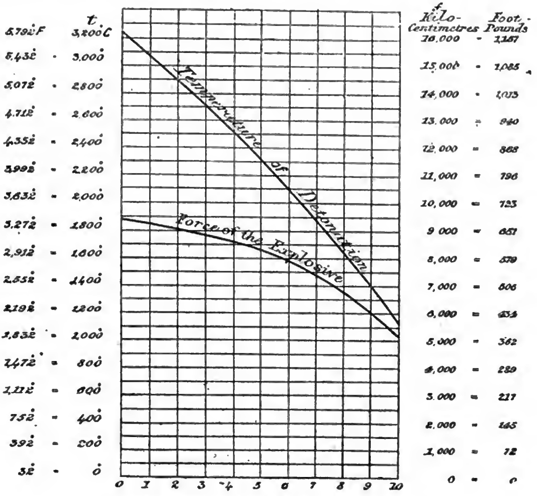


Figure 16.—Mixtures of blasting gelatine and nitrate of ammonia.

These curves are calculated by means of the formulæ given in Note A at the end of the first report of the Explosive Substances Commission. (*) It is assumed that the gelatinised nitro-glycerine contains 3 per cent. of octonitric gun-cotton and that one kilogramme (2·204 pounds) of this gelatinised nitro-glycerine disengaged 1,545 calories, and that one kilogramme (2·204 pounds) of nitrate of ammonia yields 380 calories. The gases resulting from the detonation of these two substances cannot react on each other, as both of them yield an excess of oxygen.

(1). *12 to 14 parts of Gelatinised Nitro-glycerine and 88 to 86 parts of Nitrate of Ammonia.*—The first mixture used contained 12 to 14 parts of gelatinised nitro-glycerine and 88 to 86 parts of nitrate of ammonia. The cartridges weighed 1,157·4 grains, are 1·30 inches diameter, and 3·35 inches long. The envelope of the cartridges and the packing were the same as previously described. This explosive detonated well with plugged caps containing 11·57 grains of fulminate of mercury.

[(*) See page 62.]

It is now ordinarily employed, and more than two tons have been used. The practical explosive power is 110·6, that of no. 1 dynamite being 100. The calculated temperature of detonation is 2,721 degs. F.

(2). *20 parts of Gelatinised Nitro-glycerine and 80 parts of Nitrate of Ammonia.*—Experiments have also been made with a second mixture containing 20 parts of gelatinised nitro-glycerine and 80 parts of nitrate of ammonia. The cartridges weighing 1,157·4 grains, are 1·30 inches diameter and only 2·95 inches long. The density is 1·17. The explosive power is equal to 118·6, that of no. 1 dynamite being 100. The calculated temperature of detonation is 2,980 degs. F.

(3). *30 parts of Gelatinised Nitro-glycerine and 70 parts of Nitrate of Ammonia.*—With a view of having an explosive capable of superseding blasting-gelatine, and having always the temperature of detonation less than the apparent temperature of ignition of fire-damp, 2 cwt. of a mixture of 30 parts of gelatinised nitro-glycerine and 70 parts of nitrate of ammonia was ordered. This mixture should have sufficient density, and consequently will develop a greater pressure per square inch in the shot-hole. The calculated temperature of detonation is 3,400 degs. F.

This order has not yet been supplied.

Experiments with the New Explosives with Blown out Shots.

The results obtained vary with the resistance that the stemming can oppose to the issue of the gases resulting from the explosion. This resistance is dependent on the nature and length of the stemming.

The work which the gases expend in blowing out the stemming reduces their temperature, and this diminution may be so great that certain explosives, usually giving off flame, no longer do so.

The following table summarises these experiments:—

NATURE OF EXPLOSIVE.	Length of Shot-hole.		Weight of Explosive.	Length of Stemming.	Remarks.
	Ft.	Ins.	Grains.	Inches.	
20 parts of no. 1 dynamite and 80 parts of nitrate of ammonia ...	3	3·37	2,839·5	3·94	Nothing.
do.	3	3·37	4,259·3	15·75	Very feeble light.
do.	3	3·37	7,098·9	15·75	Some sparks.
12 parts of gelatinised nitro-glycerine and 88 parts of nitrate of ammonia	2	11·43	2,314·8	0·00	Strong light.
do.	2	11·43	2,314·8	3·94	Rather strong light.
do.	2	11·43	2,314·8	15·75	Very feeble light.
do.	2	11·43	3,472·3	15·75	Nothing.
do.	2	11·43	4,629·7	15·75	Feeble light.
20 parts of gelatinised nitro-glycerine and 80 parts of nitrate of ammonia	2	11·43	2,314·8	15·75	Nothing.
do.	2	11·43	3,472·3	15·75	Feeble light.
do.	2	11·43	4,629·7	15·75	Nothing. The shot did little work.

Nature of Fumes.

The fumes resulting from these three explosives are much less injurious than those produced by no. 1 dynamite and blasting-gelatine.

The appended table gives in cubic feet at 32 degs. F. and 29·92 inches, the gases resulting from the detonation of one pound of the following explosives :—

NATURE OF EXPLOSIVE.	Water Vapour H_2O.	Carbonic Acid gas CO_2.	Nitrogen N.	Oxygen O.	Remarks.
Blasting-gelatine with 3 per cent. octonitric cotton	3·956	4·806	2·322	0·272	
No. 1 dynamite	2·931	3·524	1·762	0·304	+ ¼ pound of silica.
20 parts of no. 1 dynamite and 80 parts of nitrate of ammonia ...	7·881	0·705	3·908	1·794	+ $\frac{1}{20}$ pound of silica.
14 parts of gelatinised nitro-glycerine and 86 parts of nitrate of ammonia	8·218	0·673	4·149	1·970	
20 parts of gelatinised nitro-glycerine and 80 parts of nitrate of ammonia	7·913	0·361	4·020	1·842	

Table shewing the explosive power and the density as deduced from the experiments made at Anzin.

NATURE OF EXPLOSIVE.	Explosive Power.	Density.
Compressed powder	40	—
20 parts of No. 1 dynamite and 80 parts of nitrate of ammonia	91	0·94
No. 1 dynamite	100	1·59
12-14 parts of gelatinised nitro-glycerine and 88-86 parts of nitrate of ammonia	110·6	1·04
20 parts of gelatinised nitro-glycerine and 80 parts of nitrate of ammonia	(*) 118·6	1·17
Blasting-gelatine	125	1·43

June 1, 1889. M. FRANCOIS.

II.—ON THE USE OF THE HUNDREDWEIGHT OF EXPLOSIVES RECEIVED FROM SEVRAN LIVRY POWDER MILL.

Mixture of 10 parts of Dinitrobenzol and 90 parts of Nitrate of Ammonia.

This explosive was supplied in cartridges weighing 771·6, 1,543·2, and 2,314·8 grains. The diameter of the cartridges was 1·26 inches, and the lengths 2·87, 5·59, and 8·46 inches. The average density was 0·93. The density of the long 2,314·8 grains cartridges was practically the same as that of the smaller cartridges, and as they are less handy, it would be better to use, in the future, cartridges of 771·6 and 1,543·2 grains, the latter constituting 80 per cent. of the total weight.

Explosion was effected by plugged detonators containing 30·86 grains of fulminate of mercury, and only one incomplete detonation was observed. This explosive gives off but little fumes, and acts very well. It was found that with the same weight the explosive power was the same as that of no. 1 dynamite.

Mixture of 10 parts of Octonitric Cotton and 90 parts of Nitrate of Ammonia.

This explosive was also sent in 771·6, 1,543·2, and 2,314·8 grains cartridges, 1·26 inches diameter, and 3·15, 6·10, and 9·29 inches in length. The average density was only 0·84, and practically the same in cartridges of 771·6 and 1,543·2

(*) The trials made to determine the value 118·6 are as yet not very numerous, and there may be reason to modify it subsequently.

grains, so that the 2,314·8 grains cartridges could again be dispensed with. The plugged detonators containing 30·86 grains of fulminate have always effected very complete detonations. The fumes are rather dense, but do not cause any disadvantage to the health of the workmen.

It was found that with the same weight, the explosive power was the same as that of the preceding mixture or no. 1 dynamite.

Advantages and Inconveniences of these Explosives.

These explosives act well at the Anzin collieries, they are manufactured very carefully, detonation has always been easily effected, and their employment is very practicable.

They have the disadvantage of having a very low density, and if it is desired that the explosive should not occupy too great a length of the hole, they must be used (as they have this time been supplied) in cartridges 1·26 inches diameter, which necessitates the drilling of rather large holes, so that the drilling costs a little more than with smaller holes.

These explosives also require, for complete detonation, plugged detonators containing 23·15 or 30·86 grains of fulminate of mercury, although the other explosives detonate well with detonators of 11·57 or 15·43 grains.

There have been used for some months at the Anzin collieries, grisoutine B, grisoutine F, and grisoutine-gelatine, which are mixtures of 12 and 88, 20 and 80, and 30 and 70 parts respectively of gelatinised nitro-glycerine and nitrate of ammonia. The density, and the relative explosive power for the same weight is greater than that of the preceding mixtures. The cartridges are only 1·10 inches diameter. The degree of safety is also very great, for the temperature of detonation is not high.

The following table shews a comparison between these explosives and those from the Sevran-Livry Powder Mill :—

NATURE OF EXPLOSIVE.	Temperature of Detonation.	Density of Explosives.	Explosive Power.	Price per Pound.
	Fahrenheit.			s. d.
10 parts of dinitro-benzol and 90 parts of nitrate of ammonia	3,309°	0·93	100	?
10 parts of octonitric cotton and 90 parts of nitrate of ammonia	2,844°	0·84	100	?
12 parts of gelatinised nitro-glycerine and 88 parts of nitrate of ammonia	2,721°	1·04	111	1 6·30
20 parts of gelatinised nitro-glycerine and 80 parts of nitrate of ammonia	2,980°	1·17	118	?
30 parts of gelatinised nitro-glycerine and 70 parts of nitrate of ammonia	3,400°	1·22	122	?

The calculation of the temperatures of detonation of the Sevran-Livry explosives has been made by taking from the table of the temperatures of detonation in Mr. Mallard's report (pages 64 and 65), the results given for complete combustion mixtures of dinitro-benzol and nitrate of ammonia, and of octonitric cotton and nitrate of ammonia, and by calculating that 1 kilogramme of dinitro-benzol and 1 kilogramme of octonitric cotton, completely burnt, disengage, the first 3,988 calories, and the second 2,512 calories.

From these figures, and knowing that 1 kilogramme of nitrate of ammonia, on decomposition, gives off 380 calories, it was easy to calculate the temperatures of detonation of these mixtures where there was an excess of oxygen.

October 5, 1889. M. FRANCOIS.

LIEVIN COLLIERIES.

ON THE EXPLOSIVES IN USE AT LIEVIN COLLIERIES.

The explosives in use at Lievin are :—

1. Blasting-gelatine ;
2. Ammonia-dynamite (of Paulilles) ;
3. Grisoutine A (of Paulilles) ;
4. Grisoutine B (of Paulilles), corresponding according to the makers, to the ammonia-dynamite recommended by the Explosive Substances Commission.

Blasting-gelatine is highly appreciated on account of its powerful action. But since 1887, when experiments on the action of explosives in presence of dust alone, were made at Lievin, it was recognised that blasting-gelatine may, when it is placed without stemming in the bottom of a shot-hole, cause great ignitions of dust, the same as blasting-powder.

But, if blasting-powder strongly stemmed still causes great ignitions of dust, blasting-gelatine with even a slight stemming does not ignite dust ; very numerous experiments have established this fact.

On the other hand 2,623·5 grains of blasting-gelatine placed at the bottom of a shot-hole, and stemmed with wet clay, detonating in a mixture of air and 14 per cent. of coal-gas has not ignited that mixture (two tests made at Lievin). Unfortunately, it has been impossible to continue operating with such strong charges ; the steel block being shattered after the third trial.

It appears, therefore, that blasting-gelatine, carefully stemmed, is not so dangerous as might be concluded from its behaviour without stemming.

At Lievin, blasting-gelatine is only used in stone-drifts, and then only when heavy work has to be done. For ordinary blasting in stone-drifts and cross-cuts the various ammonia-dynamites of Paulille are used.

It is considered that the disuse of blasting-gelatine, and its replacement by feebler explosives would entail a material increase in the cost of stone-drifts, and a decrease in the speed of advancement. For this reason, and as it is certain that careful stemming greatly diminishes the danger, it is desirable that this explosive should be retained or replaced by an equally powerful explosive, at least in stone-drifts.

The following results have been obtained with the various ammonia-dynamites (of Paulille), by placing the charge without stemming in a hole, and firing in a mixture of air and coal-gas :—

NATURE OF EXPLOSIVE.	Weight of Explosive.	Percentage of Coal-gas in the Explosive Mixture.		
		10.	12	14.
	Grains.			
Ammonia-dynamite	1,172·9	Explosion.	Explosion.	—
Grisoutine A	1,234·6	No Explosion.	Explosion.	—
Grisoutine B	1,003·1	No Explosion.	Explosion.	Explosion.

The three explosives are, therefore, capable of igniting gaseous mixtures.

The latter two are a little safer than ammonia-dynamite. The series of experiments made with water tamping, have never caused an explosion.

Grisoutine A (2,469·2 grains) tried with wet clay stemming did not ignite mixtures of 12, 14, and 16 per cent. of gas. The trials being repeated, with dust in suspension in the air, there was still no explosion.

Grisoutines A and B were then tried with the Chalon safety tamping (a spongy substance containing 99½ per cent. of water). By merely placing this over the charge, without even covering it with clay stemming, which is recommended in practice, the most dangerous mixtures were not ignited with 1,234·6 and 2,469·2 grains charges.

These grisoutines from Paulilles, which are capable of igniting 12 per cent. mixtures of gas, when fired without stemming, possess, therefore, either with the wet stemming or with the Chalon cartridge, very great security.

Is this security still perfect when very heavy charges are used (4,629·7 to 7,716·2 grains), as sometimes happen in mines? The experimental apparatus was smashed by these charges, and a definite opinion cannot be pronounced.

Experiments have been made underground, with blown out shots of 4,166·7 grains, surmounted with the Chalon tamping; only a very slight flame was visible.

It is thought at Lievin, that explosives based on nitrate of ammonia, manufactured at Paulilles, possess great security *when carefully stemmed.*

They are easy to use, do not give off disagreeable fumes, and their detonation is ensured, when the 30·86 grains detonators are used.

They are considered sufficiently powerful for use in the hardest stone encountered in ordinary working, but not including cross-drifts.

VIALA.

MISCELLANEOUS NOTES
ON THE USE OF EXPLOSIVES IN THE PRESENCE OF FIRE-DAMP IN MINES.

By Er. Mallard.

I.—EXPERIMENTS AT ANZIN, ON THE FLAME PRODUCED BY EXPLOSIVES.

The experiments at the Sevrau-Livry Powder Mill were made with maximum charges of 3,086·5 grains. The explosive detonated, either unconfined or stemmed in a comparatively thin metallic tube. The conditions were, therefore, only imperfectly realised, which occur in a blown out shot, that is one only producing the effect of projecting the stemming placed on the cartridge. With the exception of those cases in which the charge, placed at the bottom of the hole, was detonated without stemming, and which should be prohibited with the utmost severity, these shots are the most dangerous in fiery mines. This is easily explained, as the mechanical work performed by the explosion gases is then at the minimum, as well as the corresponding amount of heat which is subtracted from these gases.

It was, therefore, very desirable to produce, in the profound darkness of a mine, blown out shots, heavily charged with various explosives, and to observe the greater or less flame, more or less vivid that the detonation produced under these conditions.

The Anzin Company undertook to make a series of experiments for this purpose. They took place on the 22nd and 23rd February, 1889, under the direction of Mr. Francois, in the presence of Messrs. Faucher, Aguillon, Le Chatelier, Bruneau, and the author of this report. Hearty thanks must be expressed to Mr. Francois and to the engineers under his orders, for the skill and precision with which the experiments were conducted, and to thank Mr. Guary, director of the Anzin collieries, for the cordial reception accorded.

The experiments were made in a cross-cut drift in the Bleuse-Borne Pit. The results are collected in the following table :—

Nature of Explosive.	Working Shots.				Blown out Shots.		
	Weight of Explosive.	Length of Stemming.	Thickness of stone to be lifted	Remarks.	Weight of Explosive.	Length of Stemming.	Remarks.
	grains.	inches.	inches.		grains.	inches.	
No. 1 dynamite	5,247·0	35·43	39·37	Flame	4,629·7	31·50	Flame more than 1 yd.long
20 dynamite and 80 nitrate of ammonia ...	6,172·9	19·68	31·50	Neither flame nor glow	7,716·2	15·75	Neither flame nor glow.
30 dynamite and 70 nitrate of ammonia ...	5,401·3	23·62	31·50	Slight flame	3,858·1	5·91	Sparks and rather strong glow.
15 gun-cotton and 85 nitrate of ammonia ...	5,401·3	15·75	31·50	Glow	3,858·1	5·91	Glow.
10 dinitro-benzol and 90 nitrate of ammonia...	5,401·3	19·68	31·50	Glow	6,712·9	19·68	Very slight glow.
70 nitrate of cupro-ammonia and 30 nitrate of ammonia	6,172·9	23·62	31·50	Neither flame nor glow	6,712·9	23·62	Neither flame nor glow.
Roburite	5,092·7	7·87	31·50	No flame	5,247·0	7·87	Flame.

It will be seen that mixtures of 20 dynamite and 80 nitrate of ammonia, 70 nitrate of cupro-ammonia and 30 nitrate of ammonia produced neither flame nor glow even with blown out shots charged with 6,172·9 and 7,716·2 grains. The safety promised by these explosives may, therefore, be considered as very satisfactory.

With the other explosives indicated by the Commission, blown out shots have only produced glimmers which appeared incapable of igniting fire-damp mixtures, being much less marked than those observed on unconfined detonation which, as ascertained at Sevran, only ignited fire-damp under very rare circumstances.

With roburite (*) and especially with no. 1 dynamite, blown out shots produced large flames.

II.—STEMMING WITH WATER-SATURATED SUBSTANCES.

It was proposed many years ago to ensure the safety of fiery mines, by stemming the shots either with water or with water-saturated substances.

The Explosives Substances Commission made some trials with Settle cartridges, in which the explosive is placed in the midst of water contained in an impermeable paper bag. The trials were not very satisfactory, and these cartridges have, moreover, in addition to the inconvenience of their use, the grave disadvantage of requiring a considerable increase in the diameter of the shot-holes.

Mr. Galloway proposed to form the first part of the stemming with moss saturated with water.

Messrs. Chalon and Guérin propose the use of a gelatinous substance containing as much as 95 per cent. of water, and moulded into cylinders of ·98 inch in diameter and 3·94 to 4·72 inches long. The price is 0·60d. each.

The explosive is placed between a number of these stemming cylinders, varying according to the weight of the charge; then the safety stemming is violently compressed by the wooden stemmer in such a way as to cause the gelatinous matter to flow around the explosive. Lastly, the hole is filled up in the ordinary manner.

In England, a company works the Heath and Frost patent, which is applicable to the Settle variety of cartridges, in which the water is replaced by a gelatinous substance, made of water and soap.

It has been long known, and all the experiments recently made have fully confirmed it, that all these methods of stemming are impotent with substances in which the explosive wave is not produced, such as blasting-powder. The Explosive Substances Commission shewed that, with the substances in which the detonation is rendered, so to speak, instantaneous by the production of the explosive wave, the water of the stemming does not act or scarcely acts of itself, and merely intervenes by its mass, and by the greater perfection which it assures to the stemming.

(*) According to information supplied, the roburite used in these trials was composed of a mixture of chloro-dinitro-benzol and nitrate of ammonia, corresponding to complete combustion, according to the formula :—

$$C_6H_3\,Cl\,(NO_2)_2 + 9\,N\,H_4O_3 = 6\,CO_2 + 19\,H_2O + H\,Cl + 11\,N = 922{\cdot}5.$$

This substance, finely pulverised, detonated very easily. Experiments were made at the Sevran-Livry Powder Mill, under the same conditions as those indicated in the Report of the Explosive Substances Commission. A cartridge of 2,623·5 grains suspended in the boiler, ignited a mixture of air and fire-damp containing 10 per cent. of gas. Ignition also occurred with cartridges of 3,086·5 grains of a mixture of 45 roburite and 55 nitrate of ammonia.

A 3,086·5 grains cartridge of a mixture of 22·5 roburite and 77·5 nitrate of ammonia (corresponding according to the asserted composition of roburite to 5 chloro-dinitro-benzol and 95 nitrate of ammonia), was detonated in the gaseous mixture without igniting it.

Similar mixtures might be found useful owing to their great facility of detonation.

The engineers at Anzin and those of Blanzy experimented with the Chalon-Guérin stemming.

In working shots, the use of this stemming does not suppress the great flame given by blasting-powder, but it suppresses that which is produced by blasting-gelatine and no. 1 dynamite.

The use of this stemming does not suppress the flame of blown out shots. Very small charges of blasting-gelatine (617·3 and 1,234·6 grains) stemmed at the bottom of a shot-hole and covered with three Chalon-Guérin cylinders, have still allowed the flame to be seen.

The effect of the Heath and Frost stemming is practically the same as that of the Chalon-Guérin stemming, but their use requires shot-holes 2·76 inches diameter, which is inconvenient in coal and impossible in stone.

The importance of these various methods of stemming is, moreover, much diminished, since it is now certain that it is possible to manufacture explosives which do not ignite fire-damp, even with the most imperfect stemming, and whose safety is certain with any ordinary stemming.

III.—LAUER DETONATORS.

The Explosive Substances Commission pointed out the desirability of the complete disuse, in fiery mines, of fuse for firing shots. It directed attention to the friction detonators invented by Lieutenant-Colonel Lauer, of the Austrian Engineers, and to which an Austrian Commission awarded a part of the prize of £475 offered by the Ostrau-Karwin coalowners.

The experiments with these detonators could only be made in a mine. Mr. Francois, director of the Anzin Colliery, has been good enough to procure, with some difficulty, a number of these detonators (*), and to submit them to practical tests, the results of which will be found in an appended note (†).

These results appear somewhat favourable. It will be seen that the process is not novel (indeed it is known to have been in use by artillery many years ago), and that Mr. Cousin, of Condé, had patented it in 1868. After some years their use in the Condé collieries was abandoned, in consequence of an accident caused by a workman, who, while retiring, after having prepared the shot, and holding the cord in his hand, fell and caused the premature firing of the shot, which killed him.

Mr. Johann Meyer, chief engineer for the Kaiser-Ferdinands-Nordbahn, has published an account (‡) of the results obtained in the Polnisch-Ostrau collieries belonging to the Kaiser-Ferdinands-Nordbahn, by the exclusive use of the Lauer detonator, since November, 1887.

Mr. Meyer, in the report, by which an important part of the £475 prize offered by the Ostrau-Karwin coalowners was awarded to Mr. Lauer, states that the number of miss-fires, at first considerable (14·3 per cent.), has greatly diminished, owing to improvements in the details of manufacture, until it was less than 0·1 per cent. in the month of November, 1888.

The number of detonators used has been (up to the middle of December, 1888) 82,938; six accidents only have occurred, by which one miner was disabled. Since the month of June, 1888, no new accident has occurred, and Mr. Meyer attributes this circumstance to the great improvement in the manufacture.

Two accidents occurred by returning to a missed shot, in spite of the prohibitive rule.

(*) They are manufactured by Mr. Ed. F. Csánk, Vienna.

(†) See page 153.

(‡) Oesterreichische Zeitschrift für Berg- und Hütten-wesen (16th February, 1889).

A third happened at the moment when the workman was disengaging the cord already hanging stretched.

A fourth was caused by the fall, upon the wire of the detonator, of the workman standing on a plank whilst stemming.

A fifth injured a workman remaining (against the rules) in the drift, too near and facing the shot; he was struck by a fragment of coal.

Lastly, a sixth was caused by the explosion of the cartridge during the process of stemming, probably in consequence of too violent a blow.

The use of the Lauer detonator is, therefore, not altogether without danger, and it appears very desirable that some means should be devised by which electrical shot-firing should become practicable.

IV.—HEATH AND FROST'S LAMP FOR IGNITION OF SAFETY FUSE.

The English Company working Heath and Frost's patents forwarded to the Commission a sample safety lamp, allowing of the ignition without danger of the safety fuse in fiery mines. The engineers at the Anzin collieries kindly undertook to test this apparatus, and the report drawn up by Mr. Petit is appended hereto (*).

V.—CONTINUATION OF THE AUSTRIAN AND PRUSSIAN EXPERIMENTS.

An account was given in the Report of the Explosive Substances Commission of the experiments then published, made on explosives by the Prussian and Austrian Commissions. New experiments have been made since that time, and the following are the results :—

1. *Austrian Commission.*

The very interesting experiments of the Austrian Commission were made, under the direction of Mr. Johann Meyer, at the Wilhelm Pit of the Kaiser-Ferdinands Nordbahn (Polnisch-Ostrau), from May to November, 1888. Mr. Meyer has given a short account of them in the Oesterreichische Zeitschrift für Berg- und Hüttenwesen, in the issues of the 9th, 16th, 23rd, 30th March, and 6th and 13th April, 1889.

The experiments were made, like those of the Prussian Commission, in a kind of gallery constructed on the surface with a compartment into which fire-damp was introduced from the mine. Coal-dust was spread on the bottom, not to increase the severity of the test imposed on the explosive, but merely to preserve the gallery, and because it had been observed that the dynamic effects caused by ignition of pure gas are the most violent. (†)

The cartridge was placed on the bottom, which Mr. Meyer considers as more favourable to ignition than suspending the cartridge in the midst of the gas. The French Commission did not use this arrangement owing to the fear of the rapid destruction of their boiler.

During the months of August and November, trials were made as to the safety afforded by the use of safety cartridges. It was ascertained, as the French Commission had previously found, that it was sufficient to cover a dynamite cartridge with a thin layer (·4 inch) of dry sand, to render the ignition of a gaseous mixture containing 9 per cent. of fire-damp impossible, although the exposed cartridge invariably ignited it.

(*) See page 155.

(†) Wenn nun trotzdem Kohlenstaub beigemengt wurde, so wollt man damit nur die dynamischen Werkungen der Explosion, zur Schonung des Versuchstollens, abschwächer, welche bei reinem Gasexplosionem heftiger verlaufen.

Dry sand may be replaced by various substances, among which may be mentioned: wet blotting paper surrounded by about ·04 inch of sand; coarse blotting paper doubled and steeped in water, retaining about 463 grains, &c.

A charge of 3,086·5 grains of dynamite introduced into a hole drilled in the midst of a large ingot of steel, having 6·69 inches of sand below and 3·15 inches of wet sand above it, will blow out without igniting the gas. The same result was obtained when the wet sand was replaced by dry clay.

On the other hand, 2,314·8 grains of compressed blasting-powder placed in a shot-hole drilled in the thill of a gallery, and stemmed with 23·62 inches of wet sand, ignited the gas.

These observations only confirm the facts mentioned by the French Commission, and of which a rational explanation has been given.

The experiments of the Austrian Commission have more especially been made with the following mixture:—

Nitro-glycerine	52
Silica	14
Crystallised carbonate of soda	34
	100

This mixture is called *Sodawetterdynamit*, and would have, according to tests made in leaden blocks, an explosive power less than that of no. 2 gelatine-dynamite, and greater than that of no. 3 dynamite. Consequently the explosive power may be considered as being less than half of that of no. 1 dynamite.

Mixtures of nitro-glycerine and sal-ammoniac, which is called *Ammoniakwetterdynamiten*, were also tried. Three different proportions were used:

I.	Nitro-glycerine	60,
	Sal-ammoniac	40.

The explosive force of this mixture would fall between that of no. 1 and no. 2 dynamites.

II.	Nitro-glycerine	50,
	Sal-ammoniac	50.
III.	Nitro-glycerine	40,
	Sal-ammoniac	60.

The explosive force of the last mixture would be practically equal to that of sodawetterdynamit.

The results of the tests with sodawetterdynamit are summarised in the following table:—

Proportion of CH_4 in Mixture.	Weight of Cartridges.		
	1,543·2 grains.	2,314·8 grains.	3,086·5 grains.
Per cent. 6	1 expt. N.	—	1 expt. N.
7	—	—	1 expt. N.
8	3 expts. N.	1 expt. N.	1 expt. I.
9	5 expts N.	2 expts. N.	1 expt. N. (*)
9	—	1 expt. I.	2 expts. I. (†)

NOTE.—I. signifies ignition of gas, and N. signifies non-ignition of gas.
(*) The total charge in two cartridges.
(†) The total charge in one cartridge.

A 4,629·7 grain cartridge placed, without stemming, at the bottom of a hole pierced in a steel ingot, detonated without igniting a mixture containing 9 per cent. of fire-damp.

It is a very interesting circumstance, that a 2,314·8 grains cartridge, and even a 1,543·2 grains cartridge, both made in June, and fired on the 24th August, ignited a mixture containing 9 per cent. of fire-damp.

Mr. Meyer appears disposed to attribute this anomaly to a partial de-hydration of the soda-salt which begins about 93·2 degs. F. He also only recommends the use of recently prepared mixtures. This recommendation seems difficult to follow, and would form a serious obstacle to the general use of the explosive.

Trials were made with mixtures of nitro-glycerine and sal-ammoniac. No. III., whose explosive force is the same as that of sodawetterdynamit, has not proved more safe, as a 2,314·8 grains cartridge ignited a mixture containing 9 per cent. of fire-damp. It may, however, be remarked that, with equality of safety, this explosive mixture would be better than sodawetterdynamit, as it is much more stable.

The Austrian Commission made rather numerous experiments with dynamite cartridges placed on the ground covered with coal-dust. It was ascertained that the detonation of a 771·6 grains cartridge was sufficient to produce ignition of the dust, although a charge of 7,716·2 grains of sodawetterdynamit did not produce it.

2. *Prussian Commission.*

The report of Mr. Hugo Lohmann (*) only contains the description of the numerous experiments made; neither conclusions nor summary being made.

The experiments were made with sodawetterdynamit, containing 40 of carbonate of soda and 60 of dynamite. With cartridges placed on a block of wood, and in an atmosphere containing 10 per cent. of fire-damp, the following results were obtained :—

Weight of Cartridges.	Results.
grains.	
5,015·5	Non-ignition of gas.
5,401·3	do.
6,867·4	do.
7,098·9	do.
7,407·5	do.
7,407·5	Ignition of gas.

Blown-out shots were tried, made in a hole 18·11 inches long by 2·16 inches diameter, drilled in a block of steel 27·17 inches high and 19·49 inches on the side. The block had been tested with a 5,864·3 grains cartridge of dynamite ; the maximum charge in the experiments was 3,858·1 grains. The block was built into the floor of the gallery, so that the open orifice of the hole was 1·26 inches above the surface, and that the prolongation of the axis of the hole just met the floor of the gallery at ·20 inch from the wall.

(*) Bericht über weitere in der Versuchstrecke zur Grube König bei Neunkirchen (Saarbrücken) angestellte Untersuchungen bezüglich des Verhaltens brisanter Sprenstoffe gegen Schlagwetter und Kohlenstaub. (Zeit. für Berg- Hütten und Salinenwesen, 1889. Vol. 37, page 83.)

With 3,858·1 grains charges of wetterdynamit placed in the hole without stemming, ignition of dust occurred once out of six times. In fire-damp, in 14 experiments made with 8 per cent., and 11 experiments made with 10 per cent. of fire-damp, only one single ignition occurred. The trials were, therefore, very satisfactory. In the mine it was ascertained that the power is about 1½ times that of blasting-powder, and that the working of coal is made by this explosive in good condition.

Nevertheless, two serious incidents occurred. On April 10th, the stock of one ton kept in the magazine was frozen, 165 pounds were thawed, without sufficient precaution in warm water; the carbonate of soda lost its water, the dynamite exuded, and the cartridges had to be destroyed.

Of two tons stored on July 4th, the cartridges began, at the end of August, to spontaneously exude their nitro-glycerine; and conformably to the legal regulations 418 pounds had to be destroyed. This accident was attributed to bad manufacture of the cartridge, and the insufficient quantity of silica used.

Some favourable, though insufficient, trials were made with various mixtures of dynamite with carbonate of ammonia, oxalate of ammonia, and nitrate of soda. The composition of the most satisfactory mixture was :—

Oxalate of ammonia	45
Nitrate of soda	15
Dynamite	40
	100

Other trials were made in the steel block with five kinds of explosives sent by Mr. Favier. One of these five varieties did not ignite a mixture containing 8 and 10 per cent. of fire-damp, when a cartridge of 3,858·1 grains was placed, without stemming, in the shot-hole. But the composition of this variety is not stated.

Lastly, numerous experiments have been made with various substances, viz. :— carbonite, securite, roburite, and carbo-dynamite; but the composition of these substances has been kept secret, and even appears to have varied during the course of the experiments. These results are, therefore, deprived of interest, and will not be noticed in this account.

The experiments made with blown-out shots, with or without stemming, were not very numerous, on account of the difficulties characterising them. The following are those which approach the nearest to what may happen in mines. It appears, however, interesting to report the following experiments made by the Prussian Commission, although they were carried out with explosives whose insecurity is recognised.

Weight of Cartridge.	Method of Using the Explosive.	Proportion of CH_4.	Result.
	ORDINARY BLASTING-POWDER.		
Grains.		Per cent.	
1,543·2	Without stemming.	nil.	Ignition of dust (2 expts.)
1,543·2	With stemming.	nil.	Non-ignition of dust (11 expts.)
2,314·8	With stemming.	nil.	Ignition (once in 2 expts.)
3,086·5	With stemming.	nil.	Ignition.
3,858·1	With stemming.	nil.	Ignition.
3,858·1	With stemming.	8	Explosion (once in 2 expts.)

Weight of Cartridge.	Method of Using the Explosive.	Proportion of CH_4.	Result.

Blasting-gelatine.

Weight of Cartridge.	Method of Using the Explosive.	Proportion of CH_4.	Result.
Grains.		Per cent.	
1,543·2	Without stemming.	nil.	Ignition of dust (3 expts)
1,543·2	With stemming.	nil.	Non-ignition of dust.
2,314·8	With stemming.	nil.	Ignition of dust (3 expts.)
1,543·2	Without stemming.	8	Explosion.
1,543·2	With stemming.	8	Explosion.

Gelatine-dynamite. I.

1,543·2	Without stemming.	nil.	Ignition of dust (6 expts.)
1,543·2	With stemming.	nil.	Non-ignition of dust.
2,314·8	With stemming.	nil.	Non-ignition of dust.
3,086·5	With stemming.	nil.	Non-ignition of dust (6 expts.)
3,858·1	With stemming.	nil.	Ignition of dust (twice in 12 expts.)
1,543·2	Without stemming.	5	No explosion.
1,543·2	Without stemming.	8	Feeble explosion.
3,858·1	Without stemming.	8	Strong explosion.
3,086·5	With stemming.	8	No explosion.
3,858·1	With stemming.	5	Explosion (once in 7 expts.)
3,858·1	With stemming.	6	Explosion (once in 2 expts.)
3,858·1	With stemming.	8	Explosion (once in 10 expts.)

Gelatine-dynamite. II.

1,543·2	Without stemming.	nil.	Ignition of dust.
1,543·2	With stemming.	nil.	Non-ignition of dust.
2,314·8	With stemming.	nil.	Non-ignition of dust (9 expts.)
3,086·5	With stemming.	nil.	Ignition of dust (once in 2 expts.)

Dynamite (77 per cent. of Nitro-glycerine).

1,543·2	Without stemming.	nil.	Ignition of dust (2 expts.)
3,858·1	With stemming.	nil.	Ignition (once in 27 expts.)
1,543·2	Without stemming.	5	No explosion.
1,543·2	Without stemming.	8	Explosion.
3,858·1	With stemming.	5	Explosion.
3,858·1	With stemming.	8	Explosion.

3. *The Schlesbusch Experiments.*

The Schlesbusch experiments have had some publicity, as they were made in presence of a number of Belgian engineers, and because they have been published in the *Revue Universelle des Mines* (*). These experiments were made in June, 1888, at the Dynamite Company's explosives factory at Schlesbuch, near Cologne.

The experiments were intended to shew the safety of an explosive named *Grisoutite* (wetterdynamit), whose composition was not stated. It may, however, be assumed to be identical with the wetterdynamit of the Prussian Commission; and composed of 40 parts of crystallised carbonate of soda and 60 parts of dynamite.

The explosive was placed in a hole drilled in a steel block; around which a cylinder of stout sheet iron 59·06 inches high, and 47·24 inches diameter was placed. The lower end of the cylinder was closed by a tight hydraulic joint; and the upper end was closed at the time of each experiment, by a cloth, varnished or paraffined, fastened to the rim of the cylinder by a strong india rubber band. The cylinder was fitted with doors and with plates of mica, for use as windows. The hole, after the explosive had been placed in it, was then filled up with coal-dust (which contrary to the intention of the observers greatly increased the safety); gas was introduced and mixed with the air, by a kind of fan fitted with cardboard vanes, which could be turned from the outside; this gas was heated to any required temperature, by driving steam through a small coil of three or four turns placed at the bottom of the cylinder. These preliminaries being completed, the explosive was fired by electricity, and the effects produced were carefully noted.

Grisoutite resisted successfully all the tests with charges of 3,858·1 grains, until the inside temperature having accidentally risen to 93·2 degs. F., the detonation of a charge of 3,858·1 grains (placed without stemming in the hole) ignited the gas. In two subsequent experiments, the temperature was maintained at 86 degs. F., and there was no ignition of gas; the temperature was then raised afresh to 95 degs. F., and ignition of gas was again produced.

The following day, ·732 cubic inch of crystallised carbonate of soda was placed above the charge and the stemming finished with coal-dust, and ignition did not occur even at the temperature of 95 degs. F.

A grisoutite, in which the proportion of carbonate of soda was increased, did not ignite the gas, with a charge of 3,086·5 grains instead of 3,858·1 grains.

These experiments, in which the composition of what is called grisoutite is not recorded, are of no interest in themselves, had they not demonstrated that about 95 degs. F., the decomposition of the hydrated carbonate of soda, completely modifies the properties of mixtures of dynamite and of carbonate of soda, and may more or less completely destroy the safety which they possess at lower temperatures.

4. *Summary.*

The experiments now described confirm the conclusions of the French Explosives Commission, as regards the danger which may attend the use, especially with bad or insufficient stemming, of high explosives, such as dynamite, gelatine-dynamite, and blasting-gelatine. The first series of experiments made by the Prussian Commission, which led it to formulate contrary conclusions, are formally nullified, and the results obtained in these researches remain inexplicable.

Neither in Prussia nor in Austria did the observers appear to have any knowledge of the researches of the French Commission, although they had been succinctly published in the *Comptes Rendus* of the Academy of Sciences, of 9th July, 1888.

(*) Third series, Volume V., January, 1889.

Much research has been expended on explosives whose composition is kept secret and whose individuality is only expressed by fantastic names. These names, it is needless to remark, may apply to very different substances, which are varied at the will of the manufacturer; and experiments made with such substances have, therefore, no precise scientific value, except perhaps to the manufacturer. It is very desirable that the sale of explosive cartridges, whose exact composition is not attached, should be prohibited by legal enactment. Furthermore, no experiments should be published, especially by an official commission, on explosives whose precise composition is not made known and certified by the manufacturer; in the absence of this information the experiments are entirely void of scientific value, and can only lead the user into grievous mistakes.

The Prussian and Austrian Commissions agree in recommending the use of mixtures of dynamite and crystallised carbonate of soda. This conclusion cannot be accepted, because these mixtures have not only a very low explosive force, but, further, the easy dehydration of the salt may lead to serious inconvenience. It has been previously mentioned that if an attempt is made to thaw cartridges of frozen dynamite in warm water, the nitro-glycerine is expelled from the pores of the silica, and exudes when the temperature of the water rises to 95 degs. F.; and the cartridges then become very dangerous. The same effect may occur, as has been mentioned during summer, in magazines where the cartridges are stored; and cartridges prepared some weeks back may be thus seriously damaged. It appears difficult to recommend the use of such unstable explosives, which may cause serious accidents, even in the absence of fire-damp.

It is remarkable that several other salts, easy volatilised, but more stable than carbonate of soda were, not tried, as was done by the French Commission. There is no need, therefore, to repeat the reasons which led the French Commission to abandon mixtures of this nature, and to replace the inert salt by a salt, explosive in itself, such as nitrate of ammonia; as the desired safety may be thus obtained, without sacrificing too great a proportion of the explosive force.

APPENDIX.

ANZIN COLLIERIES.

EXPERIMENTS WITH LAUER DETONATORS.

Description of the Detonators.

These detonators consist essentially of a friction match attached to a plugged detonator containing 11·57 grains of fulminate of mercury.

The friction match consists of a hollow copper cylinder *a c b b c a*, contracted at *c c* (see figure 17, double size). In this cylinder is placed another cylinder, *e d d e*, split lengthways, and to which an iron wire *f g h* is fixed. The extremity of the iron wire is flattened and bent for about ·3 inch, between the two cylinders; the part *f g* is also flattened and notched. Below the contracted part *c c* is found the fusee material M M, and below it a little disc of paper *n n* is placed. Beyond this, paper is rolled round the wire to maintain the diameter of the tube, and the whole is covered with a very strong cardboard cylinder at least ·04 inch thick. At the end, the iron wire passes through soft putty; it is bent as shewn in the sketch, and is maintained in that position by a paper cylinder *i j j i*. The working is very simple: when the iron wire is pulled the flattened and notched part *f g* is drawn through the fusee material which takes fire, and the flame, having no outlet behind, is thrown forward and causes the detonation of the fulminate in the detonator.

The Lauer detonator is attached to the cartridge in the same manner as the fuse fitted with an ordinary detonator. The stemming is done in the usual way. The end of a very supple cord from 30 to 50 yards long, which has previously been unrolled in the drift is attached to the ring of the iron wire without tearing the paper cylinder *i j j i*. Once attached, the cord is pulled, the iron wire is straightened by tearing the paper cylinder, then the roughened part penetrates the fusee material, ignites it, and the explosion is produced. The manufacturers recommend that the paper cylinder be torn and the wire straightened, before attaching the cord, but this practice appeared more dangerous than the preceding. If the drift is crooked, a little guide-pulley is fixed, so that the direction of the pull does not vary too much from that of the shot-hole.

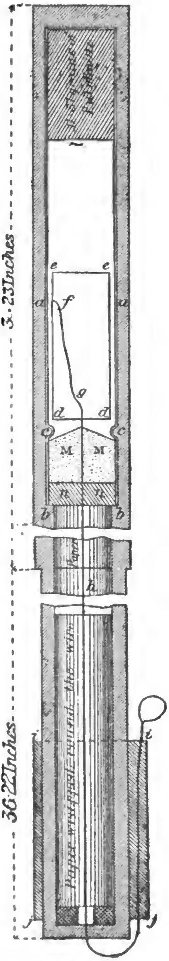


Figure 17

Figure 18 shews the arrangement of the cord in order to fire four shots at once. It requires some practice in order to achieve complete simultaneity.

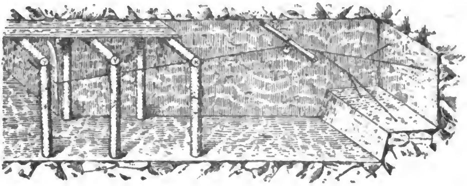


Figure 18.

Results obtained.

About 66 shots were fired without a single miss-fire. The trials were made in the Reussite, Enclos, and Bleuse-Borne pits, and in each instance the results were satisfactory. It is intended to apply this system throughout the Reussite pit, in order to judge of its practical efficacy.

Comparison of the Costs of the Various Systems of Firing, and of the Time occupied in Firing one shot.

In each instance, plugged detonators containing 11·57 grains of fulminate of mercury were used.

1. Ordinary method with safety fuse.

The cost included one detonator at ·380d., 40 inches of fuse at ·317d., and about ·048d. for touch ; total, ·745d.

The time occupied was about 8 minutes, including the time of combustion of the fuse, and for the dissipation of the fumes.

2. The Lauer process.

The expense included one detonator at 1·140d.; wear and tear of cord ·190d., and total of 1·330d.

The time occupied in firing a shot was also 8 minutes.

3. Firing by electricity (Bornhard or Ducrétet systems, tried at Anzin).

The expense included one detonator with wires 48 inches long, 2·850d., accessories and redemption ·475d., and total 3·325d.

The time occupied in firing a shot was 12 minutes on the average.

Conclusions.

The mode of ignition with the Lauer detonator costs a little more than the safety fuse method, but on the other hand it costs much less than the electrical methods hitherto used. The Lauer detonator avoids the use of safety fuse, and consequently the danger of ignition of fire-damp by the flame which the fuse projects during the combustion of the portion outside the stemming.

By combining the use of the Lauer detonator with the new explosives, it appears probable that shots might be fired in fire-damp mixtures without danger. Nevertheless, it is always prudent to suspend firing shots in the presence of gas.

The Lauer detonator, like electrical firing, permits an immediate return after a missed shot.

The principal imperfections of this process are as follows :—

1. A great number of shots cannot be fired so simultaneously as by electricity, for this system is scarcely practicable for firing more than two shots at once;

2. The Lauer detonators are 40 inches long; they are cumbersome and can only be carried with difficulty in thin seams.

3. In straight drifts, screens must be erected about 40 yards from the face to avoid projected stones;

4. It is feared that the manufacture of these detonators will not always be satisfactory. Several collieries in Austrian Silesia, where this system had been adopted throughout, have abandoned it, in consequence of defective supplies (this information is given by the director of the Karwin collieries).

5. This system possesses certain dangers to which miners are unaccustomed. An unskilful workman may cause the explosion of a shot before he reaches the shelter.

Remarks.

The method of firing shots with friction matches is not new. Mr. Cousin of Condé, took out a patent in 1868, and there were used in 1869 at the Vieux Condé collieries, 4,713 Cousin detonators, out of which there were 128 missed shots, or about 2½ per cent. A fatal accident, in July, 1869, caused this system to be abandoned.

This accident happened under the following circumstances :—A workman withdrew after preparing a shot, he held the cord in his hand when he fell down, and not having left go the cord, he caused the shot to fire prematurely, and was killed.

Such an accident might happen with the Lauer detonator.

THE HEATH AND FROST LAMP.

Use of the Lamp.

The Bickford fuse commonly used for effecting the detonation of the detonator in firing shots, is a source of danger when its ignition occurs in the presence of fire-damp. The inventors of the Heath and Frost lamp, tested at Anzin, hope to suppress this permanent cause of accident, by introducing a special arrangement, which will be described.

Description of the Lamp.

The problem to be solved consisted in using the flame of a safety lamp, Mueseler or any other, to set fire to the fuse, carefully isolating the internal chamber of combustion from the external atmosphere.

The lamp is fitted with a tube T (figures 19, 20) pierced at the height of the wick with two little holes o_1 o_2, placed on the same arc of a circle; the fuse to be kindled is introduced from beneath, the gases from the combustion of the powder escaping upwards; the upper part of the tube carries an inverted truncated cone, which supports the gauze of the lamp; and its extremity is covered with a double gauze cap.

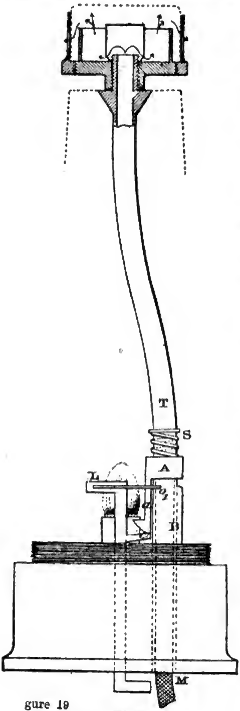
The tube T is surrounded with two cylindrical cases; the upper movable case A, provided with an arm *a*, terminated by a catch which moves a similar catch *c*, attached to the working lever L, and compresses by its movement a spring S; the lower fixed case B carries a small square guide pierced by a hole o_3 at the same height as those in the tube.

The lever L is worked by the small handle placed below the oil reservoir, and carries, soldered to its end, an iron wire F. ·04 inch diameter, curved into an arc of a circle, and controlled in its course by the guide E.

Method of Using the Lamp.

By imparting to the handle a slight rotary movement in the direction of the arrow 1, the lower cam lifts the catch of the upper movable case, the spring is compressed and the openings o_1 o_2 allow the passage of the bent wire which is to be made red in the flame of the lamp. The end of the fuse outside the shot-hole is introduced into the tube, and pushed up till it just touches the curved wire.

By working the handle in the direction of the arrow 2, the red-hot wire passes over the fuse, and sets fire to the powder, the gases from which escape by the tube; the spring brings back the movable case over the lower case; and the openings o_1 o_2, communicating directly between the chamber of combustion, and the external air are closed.



gure 19

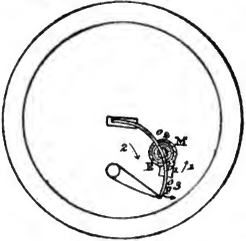


Figure 20.

Discussion on the Value of the Lamp.

1. In order that this lamp may fulfil the required purpose, it is evidently necessary that the ignited fuse be withdrawn, only after the emission of sparks is finished. A great number of trials with Bickford fuse, used at these collieries, have shewn that this emission only ceases after the fuse has burnt for a length varying from 2 to 3 inches.

It is right to ask, besides, if a defect in the fuse such as a want of continuity in the protective envelope would be material when it occurs in the length of fuse placed in the shot-hole.

To verify this, use was made of an iron tube ·98 inch diameter, and 27·56 inches long, closed by a wooden plug at one end, and entirely open at the other; the fuse to be tried was introduced into it and carefully stemmed with fine sand.

When the defect in the fuse exists in the part outside the shot-hole, a second series of projections is observed after the first sparks of ignition, when the internal flame reaches the damaged point; when, on the other hand, this defect is found in the portion placed in the shot-hole, and is covered with only ·4 of an inch of sand stemming, the second series of sparks do not occur.

The rational consequence of the preceding observations are as follows:—A maximum length of four inches of fuse should be left outside the shot-hole, so that the lamp may be entirely safe and to remove any fear from defects in the fuse. The shot-firer covers the fuse with the safety-lamp, and does not withdraw it until 4 inches of fuse are burnt.

This obligation will not usually be troublesome, for in taking-up bottom in a fiery seam, there is usually every facility for drilling shot holes 4 feet and even 6 feet long. When it is necessary for some reason to use shorter holes, the length of fuse which it will be proper to leave free beyond the hole being greater, the lamp will be quite safe, when the fuse used is of good quality.

2. Another important point is to ascertain whether the isolation of the internal combustion chamber from the surrounding air is perfect. It is obvious that in the rotary movement of the curved wire, there exists a time of whose duration varies inversely as the power of the spring, during which the tube is in communication through the holes o_1 o_2 with the chamber, and the external air. Would it not be at once safer and more simple to do away with the spring, the movable case, and to reduce to the minimum the play between the curved wire and its openings, and, lastly, to provide it with a little seat, so that its extremity just touches the wall of the tube and never passes beyond it.

Conclusions.

1. The Heath and Frost lamp affords very great safety in the majority of cases; nevertheless in firing shots of short length, much depends on the good quality of the fuse, which ought not in any case to give lateral projections of flame. It seems possible to obtain fuse of very good quality, and the English fuse which has been tried, appeared, by reason of its good covering, to solve the difficulty.

2. It is susceptible of modifications, rendering it more simple and more safe.

Anzin, 1st June, 1889. P. PETIT.

DECREE

OF THE

PRESIDENT OF THE (FRENCH) REPUBLIC

OF 26TH JULY, 1890,

RELATIVE TO THE

SALE OF DYNAMITE IN CARTRIDGES.

The President of the French Republic,

In accordance with the law of 8th March, 1875, and the decree of 24th August following, as to dynamite,

In accordance with the advice of the Committee of Arts and Manufactures,

Upon the report of the Ministers of Commerce, of Industry, and the Colonies, of War, of Home Affairs, of Finance, and of Public Works,

Decrees :—

1. That every cartridge of dynamite intended for sale must bear upon its cover an indication of the nature and proportions of the substances constituting the explosive, in order to allow of the calculation of the temperature of detonation.
2. That the Ministers of Commerce, of Industry, and the Colonies, of War, of Home Affairs, of Finance, and of Public Works, are responsible, in so far as it concerns each of them, for the carrying into effect of the present decree, which shall be published in the official journal of the French Republic, and inserted in the *Bulletin des lois*.

(Signed) CARNOT.

The Minister of Commerce, Industry, and the Colonies,
(Signed) JULES ROCHE.

The President of the Council and Minister for War,
(Signed) C. DE FREYCINET.

The Minister for Home Affairs,
(Signed) CONSTANS.

The Minister of Finance,
(Signed) ROUVIER.

The Minister of Public Works,
(Signed) YVES GUYOT.

REGULATION

OF THE

EXPLOSIVES TO BE USED IN FIERY MINES,

AND IN

DUSTY MINES WHOSE DUSTS ARE INFLAMMABLE.

Paris, August 1st, 1890.

To the Prefect of . . . .

By a circular of November 19th, 1888, which was inserted in the official journal of the 27th of the same month, my predecessor advised you of the results obtained by a special Commission which he had appointed for the study of questions relating to the use of explosives in fiery mines. In consequence of the experiments carried out under the superintendence of the Explosive Substances Commission, it has been found possible to procure for use in mines, explosives which, although not capable of giving absolute security (which one can hardly hope to obtain from these materials), permit the attainment of a degree of safety which was hitherto deemed unapproachable.

All workers of mines were supplied at the time with full information, thanks to the communication which you in due course made to them of the reports prepared by Inspector-General Mallard, by order of the Explosive Substances Commission.

Since that time, the principal explosives recommended by the Explosive Substances Commission have been extensively tried in many mines, and especially at the Anzin Collieries, where they may be said to be in current use. These trials have shewn that the question could be held as solved in practice, as it had from the first appeared to be solved in theory.

On the other hand the Government, desirous of promoting the working of mines, and of facilitating the use of the new explosives, have, by decrees of 12th June, 1890, reduced to a considerable extent the taxes upon explosives. Lastly, by a decree of 26th July, 1890, which forced the makers of explosives to inscribe upon the cartridges intended for sale the composition of their products in such a way as to allow of the calculation of the temperature of detonation, the Government have given to the workers of mines the means of compelling the manufacturers, under the penalties provided by the law of 8th March, 1875, to deliver to them only such materials as afford the necessary guarantees of safety in use.

Under these circumstances it has become possible to pass from the period of recommendation to that of enactment. It is now time, moreover, to extend the compulsory use of the new explosives, not only to fiery mines, but also to dusty mines whose dusts are inflammable.

I have, therefore, decided, in accordance with the opinion of the General Council for Mines, that in the two classes of inflammable mines which have been mentioned, the use of explosives shall be hereafter submitted to the prescribed regulations, in accordance with the form of Prefectoral Enactment annexed to these instructions.

After the receipt of this circular, you should request the Inspectors of Mines to send you, for each fiery mine and dusty mine whose dusts are inflammable, the information necessary to allow of the application of the under-mentioned regulations; and the Inspectors should shew in their proposals the maximum delay with which the decree may be carried into effect. Moreover, the said proposals should be formally notified to the worker of the mine in your preliminary order for compliance with the law.

The classification of the mine under one of the two categories above described is an *a posteriori* appreciation of fact made with comparative ease by competent engineers, but which evades, as has been long recognised in every country, a dogmatic definition *a priori*. You will observe, in regard to dusts, that in the actual state of our knowledge respecting coal-dust, it is necessary, in order that the mine may be regulated from the point of view under discussion, on the one hand that it be dusty, and, on the other hand, that the dusts arising from the combustibles produced be inflammable.

If, moreover, a worker objects to the proposed classification of his mine, and especially concerning dusts, you must refer to me.

You will have, where necessary, to enact by special decrees, simultaneous or subsequent, which can always be modified, concerning those derogations whose principles are discussed in Article 7.

These derogations are intended to permit the use either of high explosives, but less safe than those recommended by the Explosive Substances Commission, or of a stemming less than that required by Article 5; this diminution of the stemming proportionately diminishes the safety. The derogations should, therefore, only be granted when they are justified by the condition of the working-places, as regards the probable liberation of fire-damp, and only on condition of recourse to special measures of protection: special inspectors, separate ventilating areas, blasting in the absence of all workmen, &c.

You will appraise, in each case, the time which may be allowed to the mine-worker for the entire execution of the decree; it is desirable that these new regulations should be applied as soon as possible; but it is necessary to allow to the mine-worker sufficient time to procure the new explosives.

The Administration intend, so as not to impede any progress in the future, to allow at their own risk every latitude to the workers in the choice of explosives. The duty of the Administration is fulfilled when they have indicated, with all desirable precision, the technical conditions which the explosives must satisfy. If, owing to their composition, certain data are omitted in the tables annexed to this decree, for the calculation of the temperature of detonation, you should refer to me in order that I may complete them.

I do not think it useless to advise you, in the present state of the question, that the General Council for Mines have mentioned amongst the explosives actually known those which satisfy the conditions required by Article 2:—

1. Mixtures of dynamite No. 1 (75 per cent. of nitro-glycerine and 25 per cent. of silica) and nitrate of ammonia, in which the proportion of dynamite should not exceed 40 per cent. for stone work, and 20 per cent. for coal-getting;

2. Mixtures of blasting-gelatine (91·7 per cent of nitro-glycerine, and 8·3 per cent. of nononitric cotton), and nitrate of ammonia, in which the proportion of blasting-gelatine should not exceed 30 per cent. for stone work, and 12 per cent. for coal-getting;
3. Mixtures of octonitric cotton with nitrate of ammonia, in which the percentage of gun-cotton does not exceed 20 per cent. for stone work, and 9·5 per cent. for coal-getting;
4. Mixtures of dinitro-benzol and nitrate of ammonia in which the proportion of dinitrobenzol does not exceed 10 per cent. for stone work.

The explosives formed by mixtures of dynamite or of blasting-gelatine with nitrate of ammonia, should be ordered from private manufacturers.

The mixtures of octonitric cotton with nitrate of ammonia remaining a State monopoly, they can only be sold by its agents, and my colleague, the Minister for War, has stated that the National Powder Mills were able to supply any demands which might be made.

I desire you to acknowledge the receipt of this circular, a duplicate of which has been forwarded direct to the Inspectors of Mines.

The Minister of Public Works,
(Signed) Yves Guyot.

MODEL OF THE PREFECTORAL DECREE ANNEXED TO THE CIRCULAR OF 1st AUGUST, 1890.

We, Prefect of the department of . . . .

In accordance with the law of 21st April, 1810, to 27th June, 1880;

In accordance with the decree of 3rd January, 1813, the ordinance of 26th March, 1843, and the decree of 25th September, 1882;

In accordance with the law of 8th March, 1875, and the decrees of 24th August, 1875, and 26th July, 1890, upon the explosives derived from nitro-glycerine;

In accordance with the circular of the Minister of Public Works of 1st August, 1890;

In accordance with the report of the Inspectors of Mines, dated . . . . from which it follows that there is reason to consider as { fiery mine / dusty mine, whose dusts are inflammable, the workings of . . . . attached to the royalty of . . . . and to place them under the regulation for the use of explosives, provided by the circular issued by the Minister of Public Works;

In accordance with the decree dated . . . . by which we have ordered the Owner to present within . . days, his observations upon the conclusions of the above-mentioned report of the Inspectors of Mines;

In accordance with the observations made by the Owner, dated . . . . . . and the report of the Inspectors of Mines dated . . . . . . (or, considering that the Owner has allowed . . days to expire without replying),

w

Do hereby enact that—

1. The use of blasting-powder is forbidden in the hereinafter-mentioned workings of the mine of . . . .

2. The worker is forbidden to use in the workings, described in Article 1, any explosives other than detonating explosives complying with the following conditions :—
   - 1st. The products of their detonation should not contain any combustible matter, such as hydrogen, carbon monoxide, solid carbon, &c.
   - 2nd. Their temperature of detonation, calculated in accordance with the appendix to the present decree, should not exceed 1,900 degs. C. for the explosives used in stone work, nor 1,500 degs. C. for those employed in coal-getting.

3. The explosives must be enclosed in cartridges upon which are shewn the nature and the proportion of the substances of which they are composed, so as to allow of the calculation of the temperature of detonation, in accordance with the note attached to the present decree.

4. The Inspectors and Controllers of Mines must constantly assure themselves that the prescriptions of Articles 2 and 3 have been complied with, by taking from the cartridges ready for use one or more sample cartridges for analysis, and drawing up at the time an official report which shall be at once notified to the worker.

5. The stemming of the explosives ordered by Article 2 should be carefully made with plastic matter, so as to avoid blown-out shots; the length should not be less than 8 inches for the first 1,543 grains of charge, with the addition of 2 inches for each 1,543 grains additional; and should at all times exceed 20 inches.

   The detonation of the cartridge should be caused by a detonator strong enough to assure the detonation of the explosive even when unconfined.

6. No change is made in the measures of safety previously ordained, relative to the use of explosives in fiery mines, notably concerning the special shot-firer, the proof of the absence of gas before firing, &c.

7. Special prefectoral decrees, after the report by an Inspector of Mines, may authorize :—
   - 1st. In a stone drift, the use of detonating explosives other than those named in Article 2;
   - 2nd. Derogations from the ordinances of Article 5.

8. The orders of the present decree come into force with a maximum delay of . . days from the date hereof.

9. Breaches of the present decree will be established by notice from the Inspectors or Controllers of Mines whose duty it is to see that it is carried into effect.

10. Copies of the present decree will be sent to the Chief Inspector of Mines at . . . . , and to the Mayor at . . . . , who is to advise the worker, and to return to us the report of his official notification of the same.

Made this . . . . . . day of . . . .

The Prefect . . . .

APPENDIX RELATING TO ARTICLE 2 OF THE DECREE OF THIS DAY CONCERNING THE EXPLOSIVES TO BE USED IN . . . . COLLIERIES.

The temperature *t* of detonation shall be calculated, for the application of the prescription of Article 2 of this decree, in accordance with the following rules :—

F, F′, F″ being the chemical formulaæ of the substances forming the explosive, whose composition is represented consequently by the formula, $p\,F + p'\,F' + p''\,F'' + \;.\;.\;.\;.\;.\;.$, the formula of decomposition by detonation is :—

$$p\,F + p'\,F' + p''\,F'' \ldots\ldots\ldots = \alpha\,CO_2 + \beta\,H_2O + \gamma\,Cl\,H + \delta\,O_2 + \epsilon\,N_2 + \lambda\,P. \quad (1).$$

in which H = 1 gramme
,, C = 12 do.
,, N = 14 do.
,, O = 16 do.
,, Cl = 35·5 do.

and P being the weight of the solid matter left after decomposition, if there is any.

f, *f*′, *f*″ are the quantities of heat given off respectively by the formation, from their elements, of the substances that decompose on detonation, quantities of heat which are given in the following table for ordinary explosives :—

Substances.	Formula.	Quantities of heat.
Nitrate of ammonia... ...	$N_2\,H_4\,O_3$ = 80 grammes	+ 87·9
Dinitro-benzol	$C_6\,H_4\,N_2\,O_4$ = 168 do.	+ 14·5
Gun-cotton, endecanitric ...	$C_{24}\,H_{29}\,N_{11}\,O_{42}$ = 1,143 do.	+624·0
do. nononitric ...	$C_{24}\,H_{31}\,N_9\,O_{38}$ = 1,053 do.	+656·0
do. octonitric ...	$C_{24}\,H_{32}\,N_8\,O_{36}$ = 1,008 do.	+672·0
Nitro-glycerine	$C_6\,H_{10}\,N_6\,O_{18}$ = 454 do.	+197·8

The quantity of heat Q given off, at constant volume, by the detonation of the weight of explosive represented by formula (1) is given in kilogramme-degree calories as follows :—

$$Q = 94\,\alpha + 58{\cdot}2\,\beta + 22\,\gamma - (pf + p'f' + p''f'' + \ldots) + 0{\cdot}54\,(\alpha + \beta + \gamma + \delta + \epsilon). \quad (2)$$

The specific molecular gaseous heats at constant volume in gramme-degree calories are shewn in the following formula :—

For one molecule CO_2 = 44 grammes ... ... $C = 6{\cdot}26 + {\cdot}0037\,t$.

Do. do. H_2O = 18 do. ... ... $C' = 5{\cdot}61 + {\cdot}0033\,t$.

For one molecule of the perfect gases (O_2, N_2, Cl, H, &c.) occupying a volume of 22·32 litres at 0 degs. C., and under a pressure of 760 millimèters, $C'' = 4{\cdot}8 + {\cdot}0006\,t$.

The specific heat *C*, of a gramme taken as the unit of weight of the solid body, is supposed to be constant with the temperature, and equal to the value given in the following table for the substances most in use :

Substances.	Specific Heat.
Carbonate of barium	0·11
Carbonate of potassium	0·21
Carbonate of sodium	0·27
Silica	0·195
Sulphate of potassium	0·190
Sulphate of sodium	0·229

The equation, giving the required temperature of detonation, t, is then:—

$$1{,}000\,Q = [6{\cdot}26\,\alpha + 5{\cdot}61\,\beta + 4{\cdot}8\,(\gamma + \delta + \epsilon) + \lambda\,C_1]\,t$$
$$+ [0{\cdot}0037\,\alpha + 0{\cdot}0033\,\beta + 0{\cdot}0006\,(\gamma + \delta + \epsilon)]\,t^2.$$

Approved by me, Prefect of the department of . . . . for incorporation in the decree of this date, and to be used in accordance with article 2 of this decree.

OFFICERS FOR 1890-91.

President.

WM. COCHRANE, Esq., Grainger Street West, Newcastle-on-Tyne.

Vice-Presidents.

WM. ARMSTRONG, Sen., Esq., F.G.S., Pelaw House, Chester-le-Street.
T. J. BEWICK, Esq., M.I.C.E., F.G.S., Suffolk House, Laurence Pountney Hill, London, E.C.
WM. LISHMAN, Esq., Bunker Hill, Fence Houses.
G. MAY, Esq., Harton Colliery, South Shields.
J. B. SIMPSON, Esq., F.G.S., Hedgefield House, Blaydon-on-Tyne.
JAMES WILLIS, Esq., 14, Portland Terrace, Newcastle.

Council.

HENRY ARMSTRONG, Esq., Chester-le-Street.
WM. ARMSTRONG, Jun., Esq., Wingate, Co. Durham.
T. W. ASQUITH, Esq., Harperley, Lintz Green, Newcastle.
EMERSON BAINBRIDGE, Esq., Nunnery Colliery Offices, Sheffield.
T. W. BENSON, Esq., 11, Newgate Street, Newcastle.
R. F. BOYD, Esq., Houghton-le-Spring, Fence Houses, Co. Durham.
M. WALTON BROWN, Esq., 3, Summerhill Terrace, Newcastle.
T. E. FORSTER, Esq., North Jesmond, Newcastle-on-Tyne.
T. HEPPELL, Esq., Leafield House, Birtley, Chester-le-Street.
H. LAWRENCE, Esq., Grange Iron Works, Durham.
Prof. J. H. MERIVALE, M.A., 2, Victoria Villas, Newcastle-on-Tyne.
M. W. PARRINGTON, Esq., Wearmouth Colliery, Sunderland.
A. M. POTTER, Esq., Shire Moor Colliery, Earsdon, Newcastle.
T. H. M. STRATTON, Esq., Cramlington House, Northumberland.
J. G. WEEKS, Esq., Bedlington, R.S.O., Northumberland.
R. L. WEEKS, Esq., Willington, Co. Durham.
W. O. WOOD, Esq., South Hetton, Sunderland.

Ex-officio
Sir GEO. ELLIOT, Bart., M.P., D.C.L., Houghton Hall, Fence Houses.
Lord ARMSTRONG, C.B., LL.D., D.C.L., F.R.S., Cragside, Rothbury.
LINDSAY WOOD, Esq., The Hermitage, Chester-le-Street.
G. C. GREENWELL, Esq., F.G.S., Elm Tree Lodge, Duffield, Derby.
G. B. FORSTER, Esq., M.A., F.G.S., North Jesmond, Newcastle.
JOHN DAGLISH, Esq., Marsden, South Shields.
Sir LOWTHIAN BELL, Bart., D.C.L., F.R.S., Rounton Grange, Northallerton.
JOHN MARLEY, Esq., Thornfield, Darlington.
Past-Presidents.
A. L. STEAVENSON, Esq., Durham, Retiring Vice-President.

THE GENERAL AND COUNCIL MEETINGS WILL BE HELD AS UNDER:—

GENERAL MEETINGS.

October	11, 1890	...	2 o'clock.
December	13, ,,	...	,,
February	14, 1891	...	,,
April	11, ,,	...	,,
June	13, ,,	...	,,
August	1, ,, (Annual Meet.)		,,

COUNCIL MEETINGS.

September	27, 1890	Half-past 1 o'clock.
October	11, ,,	1 ,,
November	29, ,,	Half-past 1 o'clock.
December	13, ,,	1 ,,
January	31, 1891	Half-past 1 o'clock.
February	14, ,,	1 ,,
March	28, ,,	Half-past 1 o'clock.
April	11, ,,	1 ,,
May	30, ,,	Half-past 1 o'clock.
June	13, ,,	1 ,,
July	18, ,,	Half-past 1 o'clock.
August	1, ,,	1 ,,

The Secretary has instructions to call the Council later than One o'Clock on the General Meeting days if, from the nature of the business to be transacted, he considers it advisable to do so.

Transactions are exchanged with the following Societies, etc.

Académie Royale des Sciences, des Lettres et des Beaux-Arts de Belgique, Brussels.
Akademie der Wissenschaften, Munich.
American Academy of Arts and Sciences.
American Institute of Mining Engineers.
American Society of Civil Engineers.
American Society of Mechanical Engineers.
Annales des Mines.
Annales des Ponts et Chaussées.
Barrow Naturalists' Field Club.
Berg-, und Hüttenwesen in Königreiche, Sachsen.
Birmingham Philosophical Society.
British Architects, London.
British Society of Mining Students.
Canadian Institute, Toronto.
Chemical Industry, Society of.
Chesterfield and Midland Counties Institution of Engineers.
Civil Engineers—London.
Civil Engineers—Paris.
Civil Engineers—Ireland.
Cleveland Institution of Engineers.
Colonial Museum of New Zealand, Wellington.
Connecticut Academy of Arts and Sciences.
Engineering.
Engineering Association of New South Wales, Sydney.
Engineering and Mining Journal, New York.
Engineers' Club of Philadelphia.
Engineers, Society of.
Engineers and Shipbuilders and Polytechnic Society of Norway.
Engineers and Shipbuilders in Scotland,
Franklin Institute of Pennsylvania.
Génie Civil, Paris.
Geological Society of Australasia.
Geological Society, Liverpool.
Geological Society, London.
Geological Society, Manchester.
Geological Survey of India.
Geological Survey of Pennsylvania.
Geological Survey, United States.
Geological and Natural History Survey of Canada.
Geologische Reichsanstalt, Wien.
Geologiska Föreningen, Stockholm.
Geologists Association, London.
Ingénieurs sortis de l'Ecole de Liége.
Iron and Steel Institute, London.
Jaarbock van het Mijnwezen in Nederlandsch Oost-Indië, Amsterdam.
Kaiserliche Akademie der Wissenschaften, Vienna.
Kaisl. Leop.-Carol, Duetschen Akademie der Naturforscher, Halle.
Königl Geologischen Landes-anstalt und Berg Academie, Berlin.
Koninklijk Instituut van Ingenieurs, Gravenhage.
Kön. Ungarischen Geologischen Anstalt, Budapest.
L'Industria, Milano.
Literary and Philosophical Society, Manchester.
Liverpool Engineering Society.
L'Union des Charbonnages de Liége.
Magyarhoni Földtani Társulat Kiadjáwyai Budapest (Geological Society, Hungary).
Manchester Association of Engineers.
Mechanical Engineers, London.
Midland Institute of Mining, Civil, and Mechanical Engineers.
Mineralogical Society of Great Britain & Ireland.
Mining Association and Institute of Cornwall.
Mining Institute of Scotland.
Natural History Society of Northumberland and Durham.
Naturforschende Gesellschaft zu Freiburg im Bresgau.
Naval Architects, London.
New York Academy of Sciences.
New Zealand Mines Department, Wellington.
North-East Coast Institution of Engineers and Shipbuilders.
North Staffordshire Institute of Mining and Mechanical Engineers.
Oberhessischen Gesellschaf für Natur-und Heilkunde, Giessen.
Patent Office, London.
Patent Office, Melbourne, Victoria.
Philosophical Society of Glasgow.
R. Comitato Geologico d' Italia, Rome.
Revue Universelle des Mines.
Royal Cornwall Polytechnic Society.
Royal Dublin Society.
Royal Geological Society of Cornwall.
Royal Institution of Great Britain.
Royal Institution of Cornwall.
Royal Society, London.
Royal Society of New South Wales.
Royal Society of Victoria.
Royal United Service Institution, London.
Sanitary Institution of Great Britain, London.
Smithsonian Institution, Washington, U.S.
Societá Toscana di Scienze Naturali, Pisa.
Société des Ingénieurs sortis de L'Ecole Provinciale d'Industrie et des Mines de Hainaut.
Société Géologique de Belgique.
Société Géologique de France.
Société Geologique du Nord, Lille.
Société de l'Industrie Minérale.
Société Indust. du Nord de la France, Lille.
Société Scientifique Indust. de Marseille.
South Staffordshire and East Worcestershire Institute of Mining Engineers.
South Staffordshire Institute of Iron and Steel Works Managers.
South Wales Institute of Engineers.
Surveyors, Institute of, London.
Surveyors, Institute of, Victoria, Australia.
U.S. Naval Institution, Annapolis.
Victoria Mining Department.
Wisconsin Academy of Sciences, Arts, & Letters.

The Transactions of the Institute are presented to

The Belgian Government.
The British Museum.
Literary and Philosophical Society, Newcastle.
The University Library, Cambridge.
The Yorkshire College, Leeds.
Durham College of Science, Newcastle-on-Tyne.
The Museum of Practical Geology.

The Library of the North of England Institute of Mining and Mechanical Engineers has recently been carefully reorganised, and it is desired to make it as complete as possible, especially with regard to works treating on all matters relating to Geology, Mineralogy, Mining, Mechanical, and Civil Engineering, descriptions of new Coalfields, etc., etc.; contributions are therefore respectfully solicited from members and friends, especially from those who may have duplicate copies of works on any of these subjects.

DEC 1 7 1938